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U.S. AIR FORCE Project RAND

PROJECT FEED BACK

SUMMARY REPORT

March 1, 1954

R-262

Volume I

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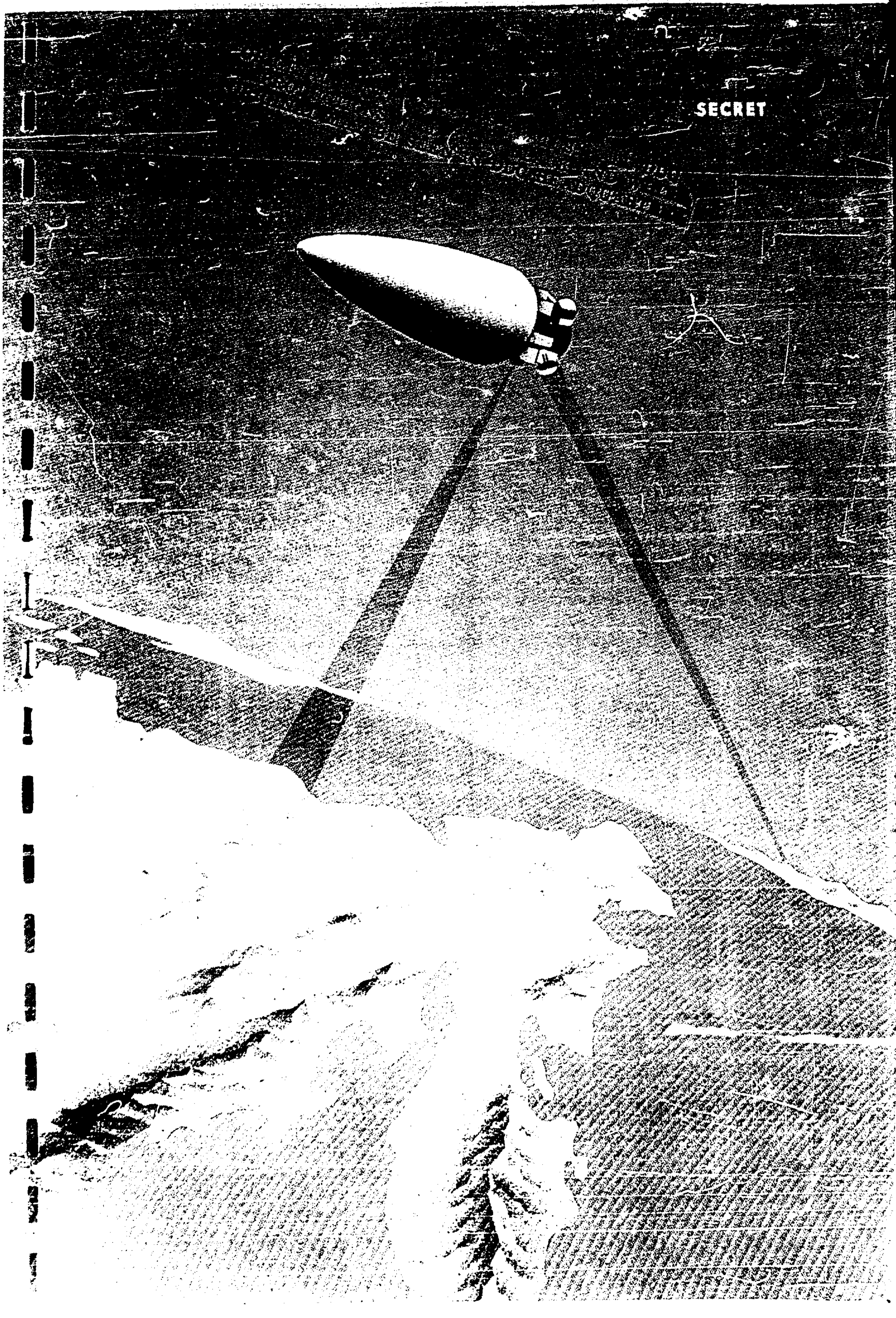
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(12) **March 1, 1954**

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Volume I

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The contents of this report have been distilled from the work of a number of organizations and individuals over a period of years. We cannot, without writing an elaborate history, give adequate credit for the thought and effort that have been applied throughout the course of the project.

Soon satellites-in-being, and later other space craft, are likely to grow from these beginnings. Therefore, it seems only right to supply a roster of those who have taken part in this study.

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The following companies also prepared reports for the Atomic Energy Commission:

Allis-Chalmers Manufacturing Company
Bendix Aviation Corporation
Frederic Flader, Inc.
Vitro Corporation

SUMMARY

An analysis of the potential of an unconventional reconnaissance method is presented here—a method whereby inaccessible points on the earth may be viewed by television from a satellite orbiting at 300-mi altitude. The current code name for this project is "Feed Back."

Primarily, emphasis in the report is on reconnaissance utility, and results of interpretation of simulated satellite photographs are included. Secondarily, a typical example of hardware needed to accomplish such a task is shown with the hope that this will serve as a guide to future investigators. It is estimated that such an accomplishment will not require radically new technology or enormous cost. A rocket vehicle of 178,000-lb gross weight is indicated. Presently available propulsion, guidance, and television will suffice. It is believed that complete development and initial operation can be accomplished in about 7 years for a cost of the order of $165 million. This cost figure is believed to be reliable within a factor of two.

The over-all conclusion to be drawn from studies of simulated satellite television pictures is that reconnaissance data of considerable value can be obtained, and that complete coverage of Soviet territory with such pictures will result in a major reversal of our strategic intelligence posture with respect to the Soviets.

RAND has been working on the satellite vehicle for 8 years. During this period the metamorphosis from a feasibility concept to a useful reconnaissance purpose has occurred. Cognizance is now being turned over to the Air Force with the recommendation that the program be continued on a full-scale basis.

CONTENTS

VOLUME I

INTRODUCTION

BACKGROUND AND PURPOSE

In 1946 the Air Force directed that Project RAND investigate the feasibility of artificial satellite vehicles. The conclusion of the study was that a large rocket would have sufficient performance to place several hundred pounds of payload on orbit.[1]*

Subsequent studies[2-13] undertaken in the following year refined these performance estimates and gave further insight into operational aspects. At that time no direct military application of the satellite was perceived. In 1948 RAND was requested to assume sole responsibility for continuing satellite work, with emphasis on possible uses of such a device, and to recommend appropriate development programs.

The most promising first use appeared to be reconnaissance by means of television. Reasonably comprehensive investigation of this scheme was carried out by RAND during 1949 and 1950[14-16] and a satisfactory utility was indicated. Study of auxiliary powerplants for the satellite was undertaken by Westinghouse Electric Corporation for RAND during this time.

To comply with the 1948 Air Force directive concerning recommendations for a development program, it was felt that further intensive investigations of certain critical elements of the reconnaissance satellite would be required.

These investigations, conducted during the period from mid-1951 to the present, included:

1. Studies of the suitability of television for reconnaissance by satellites, made by Radio Corporation of America for RAND on subcontract.
2. Studies of auxiliary powerplants to supply electricity to vehicle-borne equipment, made by Allis-Chalmers Manufacturing Company, Bendix Aviation Corporation, Frederic Flader, Inc., and Vitro Corporation for the AEC at Air Force request.
3. A subcontract from RAND to North American Aviation, Inc., to study an attitude-sensing and control system for the orbiting vehicle.
4. A prime contract from the Air Force to North American Aviation, Inc., to study a take-off guidance system to place the vehicle on orbit.

*For references, see p. 173.

5. Various supporting studies by RAND and its consultants on political and psychological effects of satellite operations, weather analysis by satellite television pictures, properties of the upper atmosphere, effects of meteors on satellite operation, alternative uses for satellite vehicles, and component characteristics.

Results of this work confirmed many of the assumptions made in previous analyses and suggested further avenues of exploration needed for the components unique to satellites.

This report should be viewed as being background for future specific development effort and not as being an accomplished preliminary design or systems analysis.

This does not mean that the horizons of the project to date have been so narrow as to preclude exploration of several ways of accomplishing a given operation. Indeed, nearly every avenue of investigation that could be considered as being within the limits of the scope and time allowed this project to date has been traversed. In many cases a particular component postulated in earlier reports has again appeared here. However, an endorsement of the component is not necessarily implied, since alternative schemes may have been considered as being more appealing at other times.

In no case should the specific numerical values used be accepted as rigidly governing future Feed Back designs.

A brief over-all description of the Feed Back reconnaissance scheme is presented next in this Introduction. The remainder of Vol. I contains the operational and developmental aspects of Feed Back. Volume II is a compendium of pertinent design information and is intended to record the extent of RAND (and other) efforts concerning components.

DESCRIPTION

A summary of the characteristics of a satellite reconnaissance scheme will be given here. Henceforth this method will be referred to as "Feed Back," which is the current (unclassified) code name for the project.*

Feed Back is presently conceived as being an integrated scheme for obtaining pioneer pictorial reconnaissance of potential enemy territory. As such it includes not only the television-equipped satellite vehicle(s), but also ground facilities

*A special note on the need for secrecy is presented below, under the heading "Program Considerations," p. 141.

for handling and evaluating information gathered. It is felt desirable to describe Feed Back, starting with the nature of the output, i.e., the intelligence information, and finishing with the elements used to obtain this information.

Figures 1 and 2 are facsimiles of pictures which could be obtained by means of television from a satellite vehicle circling the earth every 90 min at an altitude of 300 stat mi. Such pictures could be obtained at rates of 100,000 or more per day and within a few weeks could cover the territory of interest to U.S. intelligence agencies. Technical details concerning the simulation techniques used to obtain these pictures are presented later in this report.

Figure 1 is a section of Moscow 10 mi square, and Fig. 2 is a portion of Detroit 5 mi on a side. The latter picture obviously has the greater quality of detailed information because of its larger scale. However, four times as many pictures of this larger scale would be needed to cover an area such as is shown in Fig. 1.

Withholding until later a discussion of the interrelation of optical parameters, it is pertinent here to give an idea of the information that can be extracted from pictures of the quality level indicated by Figs. 1 and 2.

At first the satellite would probably provide pioneer reconnaissance, meaning the determination of the existence, approximate location, and general nature of targets and activities.

It is certain now that the satellite television could be used to see and recognize the following features:

1. Airfields of all sizes, and possibly indications of activities (the presence of large planes, etc.) on airfields.
2. Industrial concentrations, isolated or within cities.
3. Large plants, and possibly some indication of types of plant.
4. Harbors, and facilities such as graving docks and large ships.
5. Transportation, power, and communication networks, including switching yards, bridges, canals, power lines, and perhaps activities in these fields.
6. Urban areas, including the density of built-up areas.
7. Large military installations, including military camps and explosive storage.
8. Cloud pattern and structure in considerable detail.

Features of interest in Figs. 1 and 2 which could legitimately be detected by well-trained interpreters are indicated on the accompanying annotated sketches.

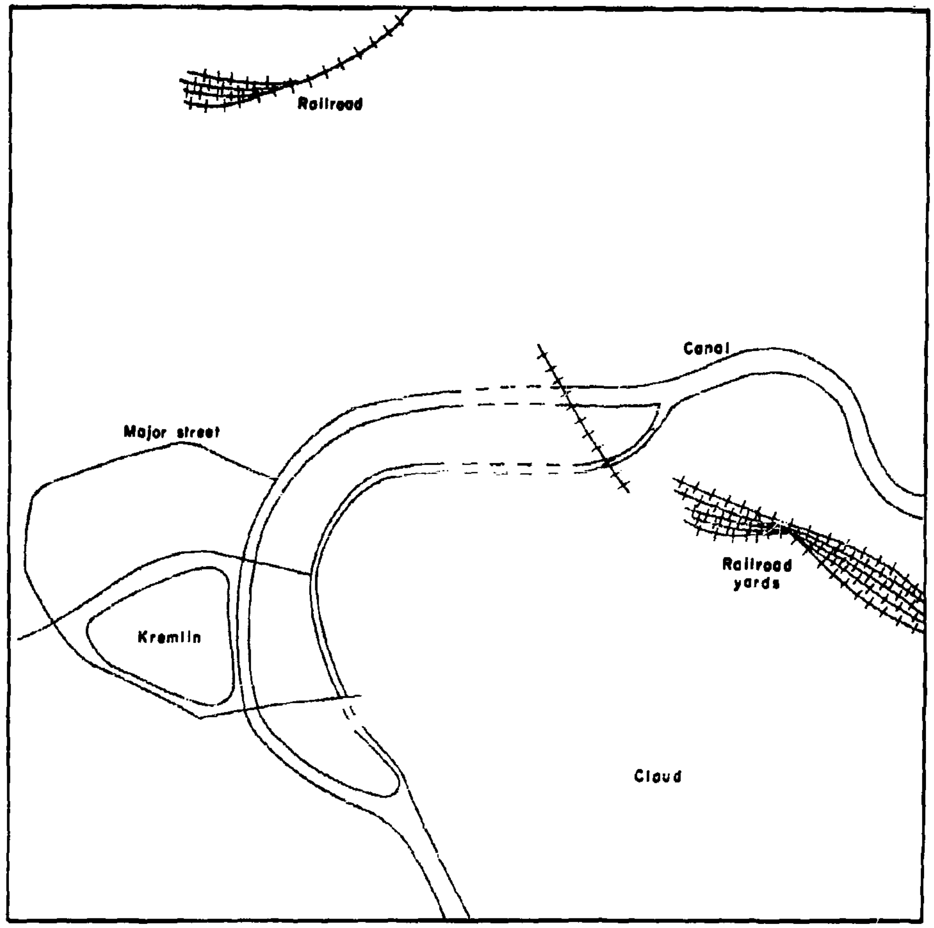


Fig. 1—Moscow, USSR (photocathode scale: 1:523,000)

411

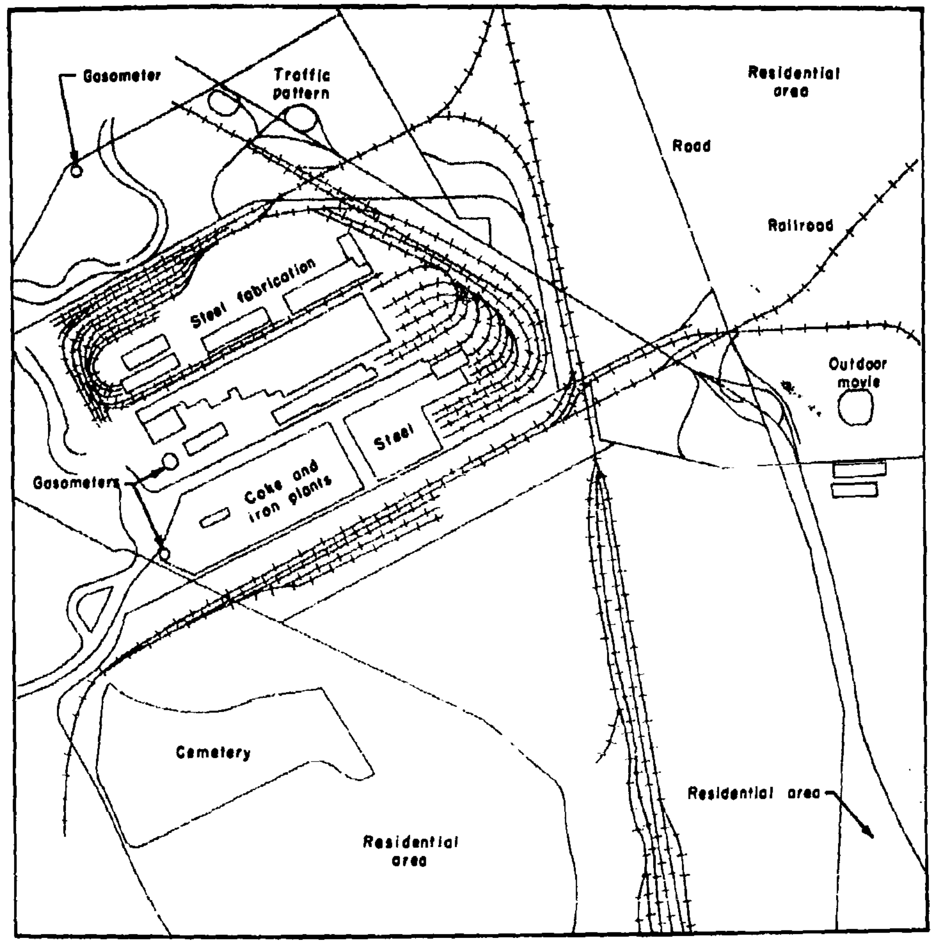


Fig. 2—Coke, iron, and steel plant at Detroit, Michigan (photocathode scale: 1:234,000)

40

A more extensive series of simulated pictures, including interpretation and explanation, is presented in the next section.

In addition to the subject content of the television pictures, Feed Back would provide a unique target-mapping capability which could well be the only such capability compatible with contemporary bombing operations.

Cloud patterns appearing in the pictures could be expected to yield valuable aid to prediction of weather in the interior of Russia. If necessary, the picture scale could be reduced so that a complete cloud mosaic of Russia would be obtained daily. Explanation of the method of using cloud pictures for weather analysis and prediction, as well as the mapping capability discussion, may be found under "Nature and Value of Feed Back Television Reconnaissance Information," page 17.

Photographic interpretation of Feed Back pictures and dissemination to principal users would be performed in a central intelligence center. The present concept of such an activity includes:

1. Construction, from the individual frames, of large-scale mosaics of enemy territory and constant improvement of these by substitution of later and better pictures.
2. Interpretation of selected pictures for content and relation with other intelligence data.
3. Permanent storage and indexing of all original and extracted data.
4. Preparation of mapping and charting data from knowledge of the picture content and location.

Pictures handled in this way at the intelligence center would be received from one or more Feed Back ground communication stations. These stations would serve the primary function of receiving all signals from the orbiting vehicle. Information as received would be placed on a master recording, perhaps in duplicate. Magnetic tape or photographic film may be used, but the flexibility and simplicity of tape recording makes this method the more attractive.

Monitoring devices located within each communications station would allow certain types of preliminary analysis and interpretation to be performed. Small-scale mosaics of extensive areas, generated as soon as data were received, would facilitate rapid weather analysis by permitting the examination of cloud patterns and structure.

In addition to the above functions, each station would also act to track and locate the vehicle, to predict its future path, and to send command instructions

concerning the operation of equipment on board. Communication between the satellite and the ground stations, as presently conceived, would be carried out by a two-way link consisting essentially of the television transmitter and a receiver aboard, and a tracker and a command transmitter grouped at the ground station. Microwave frequencies and narrow-beam techniques would aid in protecting the link from jamming or interception.

The location and number of ground stations is influenced by both physical and operational requirements which will be discussed in detail later. If the vehicle was incapable of storing television signals, then direct transmission would be necessary, and a number of receiving stations, perhaps five, near the periphery of Russia would be required. If, on the other hand (as preferred), the information was recorded in the vehicle and transmitted after suitable delay, one station in Alaska or two in the United States proper would fulfill pick-up requirements.

On board the satellite, the basic equipment required to complete the intelligence data chain would probably be:

1. A scanning mechanism to obtain a series of individual images of the ground, formed in a checkerboard pattern some 200 mi to either side along the path of the vehicle (see Fig. 3). Motion of these images would be "stopped" relative to the television camera during exposure. The basic dimensions of the ground scenes are at present about 7 by 10 mi, with moderate allowance for overlap.
2. A television camera to convert the optical images presented by the scanning device to electrical signals which could be transmitted directly to the ground station or stored for delayed transmission.
3. A data-storage system of the magnetic-tape video recorder and playback variety which could store all the pictures taken by the television camera during several passes over Russian territory and later transmit these pictures while in contact with a ground station on U.S. territory.

A satellite vehicle, of course, would move in a definite orbit as does any astronomical body. A circular path at a 300-mi altitude would be desired. The use of an 83° inclination of the orbit plane with the equator and a westward direction of motion of the vehicle in the orbit would make it possible always to view interesting ground targets in strong daylight. At this inclination the orbit plane would regress (rotate with respect to outer space) in synchronization with the earth's progress around the sun, permitting the desired constant aspect of the orbit relative to the sunlit portion of the earth. With the 400-mi-wide scan-

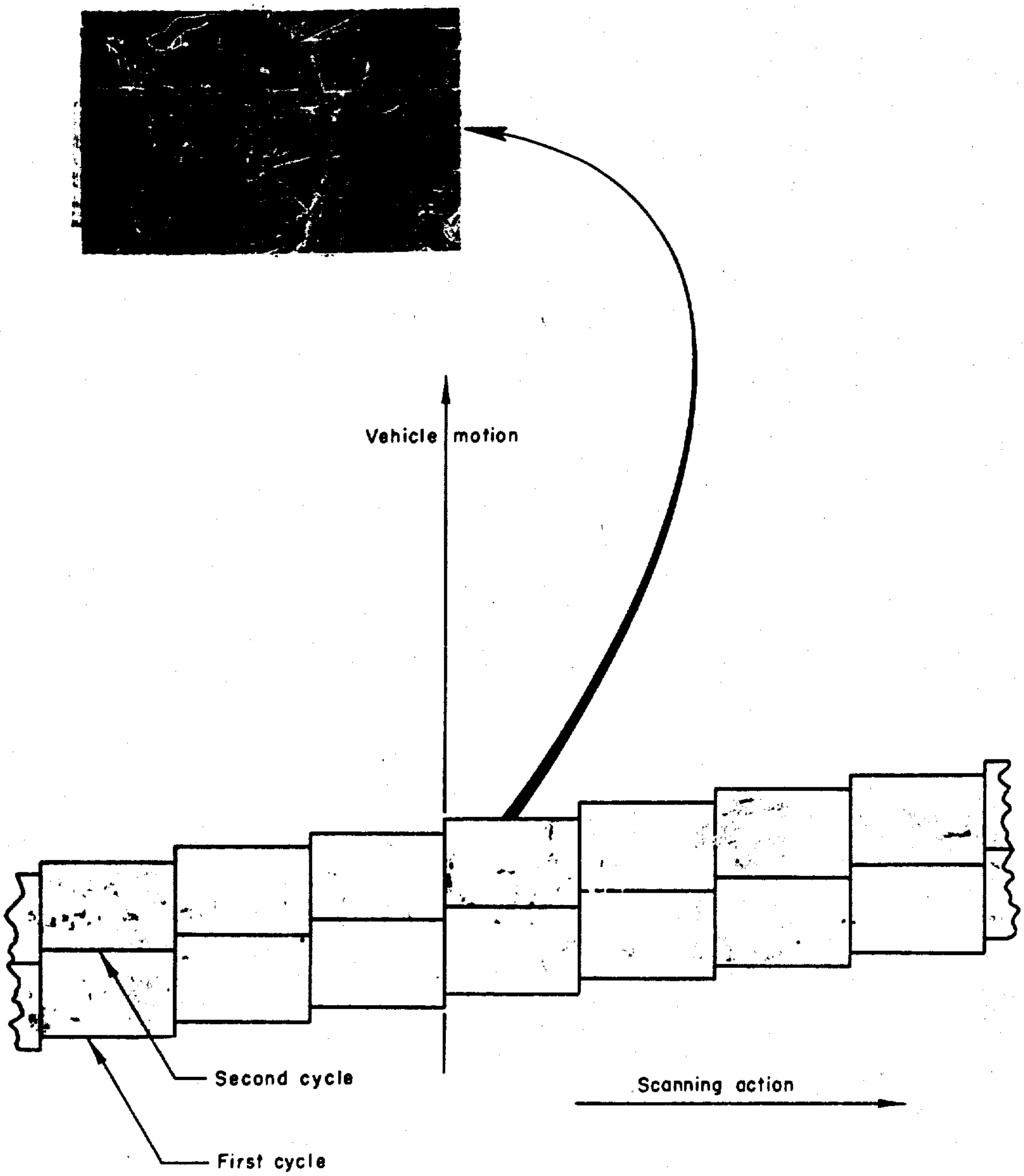


Fig. 3—Picture-scanning pattern

ning band and pictures of the scale of Fig. 1, the vehicle could conceivably view all ground targets of interest in 3 days. Due to weather veiling, the number of days needed would be increased severalfold—perhaps to as long as a month. For pictures of the scale of Fig. 2, a year might be required for complete coverage by a single vehicle.

An assembled satellite vehicle as depicted in Fig. 4 is seen as a two-stage rocket of conventional design and would weigh about 178,000 lb at take-off.

Fig. 4—Schematic of satellite vehicle

Main rocket motors required for the booster (probably two) would be similar to those at North American Aviation, Inc., presently under contract for the Atlas Project, i.e., about 120,000-lb thrust, gasoline-oxygen type. In addition to these main motors (which would be fixed), there would be two gimbaled units, each of about 22,500-lb thrust. A single main rocket motor for the second stage would also use gasoline-oxygen and be of 36,000-lb thrust. The satellite (second) stage would have a dry weight of 4500 lb, including about 1500 lb of equipment comprised of guidance and control for flight path and attitude, television cameras, recorder-playback, transmitter, command receiver, antennas, and auxiliary powerplant system.

The specific make-up of the equipment carried into the orbit would, of course, depend on the mission of the satellite vehicle. In this study, television reconnaissance has been predicated, and an optical scanning system projecting ground scenes into two Image Orthicon cameras has been assumed. The remainder of the components on board would be so designed that other payloads could be introduced into subsequent vehicles. For example, it would be necessary to include a power source supplying several kilowatts of electricity (visualized here as a nuclear reactor supplying heat for a closed-cycle mercury turbogenerator), a means of stabilizing the vehicle in attitude (having both sensing and motivating components), and a transmitter-antenna system for microwaving data to the ground. A detailed description of these items will be found in Vol. II.

A satellite would be launched onto its orbit from a base presently visualized as being similar to the White Sands or Patrick AFB facilities. No unusual handling problems are anticipated. Take-off could be anywhere in the zone of latitudes to be brought under surveillance; a base in Alaska or perhaps on

the U.S. Gulf Coast would be desired, for reasons of an operational nature to be described later.

Ascent maneuvers would be controlled by a self-contained guidance system of the inertial type, the components of which are well known today. After a vertical launching, the vehicle would turn toward a horizontal path within the desired orbit plane, as indicated in Fig. 5. Upon the completion of two stages of burning, as indicated, the craft would coast on a gently curving ascending path to the desired 300-mi altitude, where a very short, final application of power would adjust the speed for stable orbital conditions. The ascent guidance operation need only be capable of producing an accuracy of ± 25 mi in altitude and about 0.1° in azimuth.

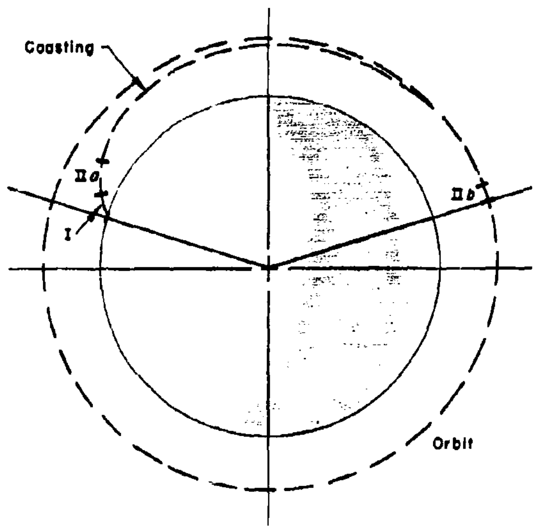


Fig. 5—Schematic of satellite trajectory

A development effort for Feed Back of scope and pace comparable to those of present major missile projects should yield an operational capability such as that described above in 6 to 7 years. Special requirements in connection with a development program are given under "Program Considerations," page 141. Costs, including all development and the operation of the system for a full year, total an estimated $165 million, depending on the number of vehicles launched. Although these numbers may be modified in the light of future development, we have confidence that they are not in error by more than a factor of two.

The high- and low-resolution systems are almost identical as to equipment that must be carried in the vehicle. Assuming that adequate reliability could be achieved, there is little gain to be made by specifying a short operational life (say, 1 month) as compared with a long life (say, 1 year). Our development time and cost estimates therefore apply to either case.

NATURE AND VALUE OF FEED BACK TELEVISION RECONNAISSANCE INFORMATION

In this section, considerations of the application of satellite pictures to photoreconnaissance (recognition of ground scenes), to mapping (location of ground data), and to weather analysis will be given in sequence. The anticipated value of reconnaissance data obtained by these latter means will be subsequently discussed.

Discussion here is of a qualitative nature, and several examples of simulated satellite television pictures are shown. Technical analysis of the physical limitations of television and validity of the simulation technique is given under "Vehicle-borne Facility," page 93. The methods of acquisition and handling of information and the expected development requirements will be discussed under "Operational System Study," page 85.

PHOTOGRAPHIC RECONNAISSANCE INTELLIGENCE

Early explorations of the possible military utility of satellites quickly indicated their role as reconnaissance devices. However, formidable technical barriers presented themselves when the need to recover photographic film records from the vehicle was considered. This difficulty would be obviated if television were adopted as the means for gathering data.

First examinations of the value of satellite television[14][16] entailed considerable effort to define on a quantitative basis the quality of the information to be expected. Much valuable work has been done along these lines with regard to conventional aerial photography. However, because the quantitative definition of image quality (e.g., in terms of minimum resolvable dimension) must be correlated with subjective impressions, and further because the scale and general appearance of satellite television pictures would be unfamiliar to the photographic interpreter, an empirical rather than an analytical method was first devised.[17] This method, consisting in simulating the type of picture to be expected from satellite television, has been improved along with concurrent developments in television and forms the basis for the present concept of the expected value of Feed Back reconnaissance data.

To simulate satellite television pictures, prints of conventional aerial photographs were viewed from a distance by a television camera; the television image of each of these was then photographed from the monitor scope of the television system. By appropriate choice of the original prints with regard to scale, resolution, and contrast, and by adjustment of lighting and optical arrangement, the experiment approximated expected viewing conditions from the satellite.

The immediate questions raised by the simulated pictures concerned their relation to conventional aerial photographs. After lengthy consideration of the different information transfer processes involved in Feed Back and conventional aerial reconnaissance, it became apparent that scale was of primary consequence compared with the difference between television and photography.

Conventional aerial reconnaissance has dealt largely with pictures at scales from 1:1000 to 1:50,000. A 9 by 9-in. photograph, taken at 40,000 ft with a 6-in.-focal-length camera, shows a ground scene about 11 mi on a side at a scale of 1:80,000. Pictures of this scale are at or beyond the boundary of acceptability for conventional aerial photographic interpretation.

By comparison, a satellite television picture of the same ground area (11 by 11 mi) taken from an altitude of 300 mi with a 27-in.-focal-length television camera would appear very much as though taken on 1 by 1-in. photographic film at a scale of 1:700,000. When enlarged to useful print size, the degradation of the image is obvious. Larger-scale pictures, showing a ground scene of much smaller dimension (say, 1.5 by 1.5 mi) could be obtained from the satellite by use of more complicated optical elements and at the expense of a much slower ground-coverage rate. The corresponding scale of such pictures would approach 1:100,000.

It is apparent, then, that the Feed Back interpreter would be working in a scale spectrum which would start at the present conventional threshold of acceptability and extend below to even poorer quality. His procedure would differ in many respects from that used for interpreting conventional aerial photography. However, the need for such a reorientation in method is not restricted to Feed Back, but occurs today in a similar way in the field of radar photography and will be required for many wide-coverage, limited-resolution reconnaissance schemes. The major change in technique involves the identification of many items by indirect methods, such as recognition of their relationship to known subject matter in typical patterns or layouts, rather than by

positive identification of the isolated item. In many cases extensive area coverage aids in reliable identification by providing lead-in information to the subject in question.

Examples of simulated satellite television pictures shown in Figs. 6 through 30 represent two plausible scales, 1:500,000 and 1:125,000, where scale is defined as the ratio of the dimensions of the image on the surface of the photosensitive area of the television camera to the corresponding dimensions of the object on the ground. For display and interpretation the pictures can be photographically enlarged to any convenient size. The pictures as shown include interesting variations of subject content and operational conditions and are representative of what may be expected under favorable viewing conditions (degradation of quality due to haze and inferior lighting is discussed under "Vehicle-borne Facility," page 93). In many cases the larger-scale pictures are excerpts of interesting portions of the smaller-scale ones. Accompanying each picture is a drawing depicting in brief some of the more significant features shown in the photograph. The drawings were prepared by an experienced photointerpreter.

As a result of study of these and hundreds of other simulated pictures, some broad conclusions can be drawn regarding what can be detected and identified. These conclusions will be discussed below under headings indicating major items of interest in military aerial photographic interpretation.

Lines of Communication, Distribution, and Transportation

Highways, roads, railroad rights of way, pipeline and power-line clearings, irrigation and drainage canals, and inland-waterway canals are usually discernible in the pictures from their typical line or thread-like pattern. However, because of their similarity they must often be distinguished by sharpness of curvature, location relative to other known objects, implications of functional intent, etc.

Examples of most of the above items are found in Figs. 6, 7, 8, and 9. Typical of the interpretation techniques necessary is the differentiation of the power line from the adjacent highway in Figs. 8 and 9. Interpretation was effected here by noting the continuous nature of the highway through both cleared and forested areas as opposed to the intermittent aspect of the power line when passing out of one type of area into another.

Examples of road and railroad bridges are shown in Figs. 6 and 7. At the small scale (1:500,000), bridges are usually apparent but are indistinguishable in many cases as to type. At the larger scale (1:125,000), Fig. 7, it is possible to determine not only the functional use of the bridge, but also details, such as the number of piers and length of each span. In some cases special bridge types, such as draw, swing, or lift, can be identified.

Railroad rights of way can be distinguished in many small-scale pictures (see Figs. 6 and 16). In large-scale pictures (see Figs. 7 and 10), railroad rights of way are readily identified; and, in addition, such facilities as overpasses, underpasses, switching and sorting yards, roundhouses, repair and service shops, freight yards, and passenger depots can often be identified.

Dikes, levees, and drainage canals are often distinguishable, as shown in Figs. 6 and 7.

Inland waterways, such as rivers, are easily recognized and can be identified by dams, canals, and locks, as seen in Figs. 11 and 12.

Harbors

Figures 13, 14, and 15 are pictures of harbors. At the scale of 1:500,000 harbors are always apparent, and such harbor-protective structures as breakwaters, jetties, and moles are identifiable.

Other features usually recognizable at this scale are piers, and ships and boats under way. At the larger scale (Figs. 14 and 15), such additional features as ships tied up at piers, ships under construction on ways, graving docks, floating dry docks and transit sheds, marine railways and roads, shipbuilding yards, and other industrial features of harbor areas may be observed. By repeated coverage reliable estimates of the level of harbor activity could be made.

Airports and Airfields

In general, all the Feed Back pictures having been studied, airports and airfields of the all-weather type (with hard-surfaced runways) can be readily identified; in addition, more primitive airfields having dirt or grass runways can usually be seen. Figures 6, 8, 16, 22, and 25 at 1:500,000 all contain airfields. In these, runway patterns, taxi strips, service and parking areas, hangars, and the limits of area devoted to airport activity can usually be identified. In Figs. 9, 17, and 23 at 1:125,000, additional information regarding air operations, such as the presence of large aircraft, revetments, smaller service buildings, wing/engine shelters, and hardstands with their probable function can be determined.

If Soviet air operations continue to be typified by the present Feed Back pictures, it should be possible to maintain continued surveillance over their air facilities and thereby to obtain and maintain a reliable estimate of their air potential and its deployment.

Urban Areas

Urban areas, in contrast to rural or natural undeveloped areas, are easily distinguished in all the Feed Back pictures. At the smaller scale the limits of urban build-up are apparent with a fair degree of accuracy. Street patterns, larger streets, and major railroads within urban limits can be identified. A reasonably accurate separation of the urban area into residential, commercial, and industrial districts can usually be accomplished. Examples are shown in Figs 6, 13, and 18. At the larger scale (see Figs. 7, 15, and 24), the separation of activity in the city is more positive, and such details as smaller streets and buildings can be differentiated.

Industries

As noted above, it is often possible to identify as industrial some districts of built-up areas at the smaller scales. Large industrial establishments in more isolated locations can often be detected—e.g., the plant in Fig. 18. However, at the larger scales much industrial activity can be more readily determined in the pictures. The coke, iron, and steel industry (shown in Fig. 19) and other industries such as petroleum refining, explosives manufacturing, shipbuilding, etc., which cover large areas with distinctive patterns can usually be identified in larger-scale pictures.

Military Installations

The larger military establishments, such as military airfields, navy yards, and army camps and forts are often revealed by their distinctive size and layout, as exemplified in Figs. 16, 20, and 21. More detailed information concerning the military nature of various establishments is available from the larger-scale pictures (e.g., dispersed and revetted explosives storage, dispersed parking of aircraft, and the pattern of military barracks and camp construction).

Deception

The simulated television pictures discussed above were all examples of infor-

mation which would be likely to be obtained under normal conditions of fair weather and the absence of countermeasures. The deception of any aerial reconnaissance method can be effected by means of concealment, camouflage, or decoys. Deception as a countermeasure against Feed Back would probably be more effective than it would be against conventional aerial photographic reconnaissance, which usually employs larger scales. However, deception employed against Feed Back would be difficult and extremely expensive, if it were to be at all effective. An example of the failure of camouflage to deceive the satellite television is shown in Fig. 24. This picture of the Los Angeles International Airport and surroundings was taken during World War II, when the area was camouflaged with painted street patterns, netting between and surrounding buildings and over parking areas, etc. The effectiveness of this particular job of deception is negligible, as it is really difficult to tell that camouflage is present, whereas most major features of the airport and adjacent factories are apparent.

It should be noticed that, in this particular simulation, the camouflage was actually penetrated by the aerial camera which made the photograph for the television picture. However, the spectral color response characteristics of the television tube are sufficiently like those of photographic film to make the simulation realistic.

An example of a more effective job of deception is shown in Figs. 25 and 26. On the original aerial photograph, from which these simulated satellite television pictures were made, aircraft could be detected, parked in the indentations in the dark forested area along the road. In Fig. 26, which is an enlarged view of the area of interest, the indentations to be seen might arouse suspicion, since the area is adjacent to the airfield (as shown in Fig. 25); the presence of aircraft would be suspected although not clearly shown.

Effects of Repeated Coverage

Feed Back would offer an opportunity to obtain repeated views of the same ground scene. Thus natural or man-made changes could be detected and comparison should aid in their interpretation.

New major construction activities, unless carefully camouflaged during the construction process (a most difficult procedure), can usually be noticed by comparison of succeeding pictures of the same area. By comparing Figs. 25 and 26, which were taken over Aken, Germany, during (Fig. 25) and after (Fig. 26) the last war, it can be discerned that the field between the airfield

and the dark forested area (mentioned above) shows indication of construction activity in Fig. 26.

Figures 27, 28, 29, and 30 are pictures of Big Delta Air Base, Alaska, during April, 1948, September, 1946, September, 1948, and February, 1949, respectively. It may readily be seen, in the case of airfields in particular, that snow on the adjacent terrain increases the detectability of runways in constant use while decreasing that of roads and taxi strips either not cleared or not heavily used.

In addition to the effects of snow, other natural changes, such as the presence or absence of foliage throughout the seasons and change in the moisture content of the soil, can lead to ease or difficulty of interpretation. For example, the power line in Figs. 8 and 9 was identified largely by observation of the clearings through forested areas. If the trees in these areas were deciduous and were bare of leaves, the contrast to the cleared areas would be reduced, rendering interpretation more difficult.

Special Considerations

In conventional aerial photography, the use of special techniques, particularly color and stereographic presentations, has been undertaken in an attempt to increase the value of the pictures. It is doubtful if these methods would significantly improve Feed Back pictures, the basic reason being their reduced scale.

Color contrasts are greatest for small objects, which in many cases would be near the limits of the resolving power of the Feed Back equipment. In order to substitute color contrast for gray-tone contrast in television without sacrificing the resolving power, additional equipment and increased bandwidth would be required. It is believed that such additional equipment would not pay off in satellite operations.

Vertical resolution obtainable in stereographic satellite television pictures would not afford any improvement in the detectability of most man-made objects. Since stereographic presentation requires overlapping coverage of the areas in question, it is again doubtful that such presentation would be desirable. One exception would be in the construction of small-scale topological maps, in which stereographic models would permit determination of terrain contours to a fair degree of accuracy.

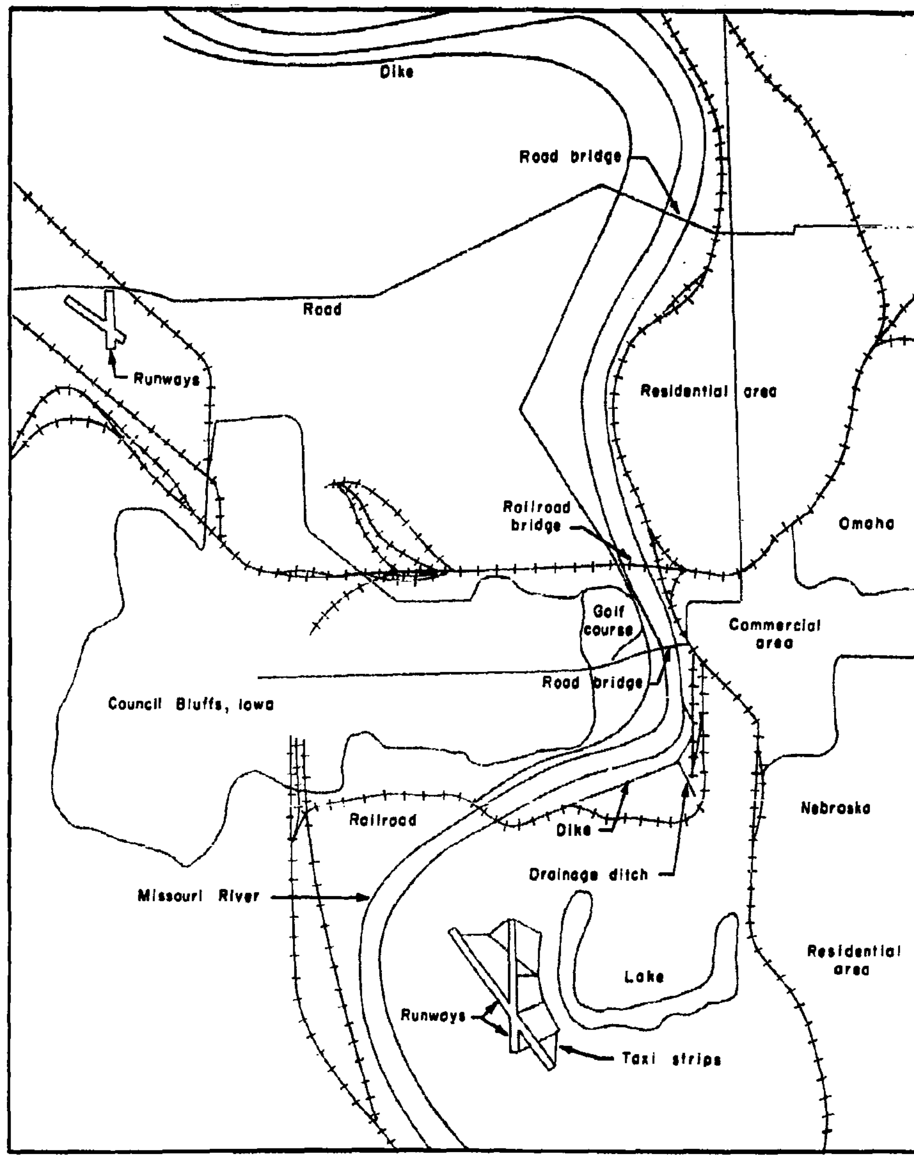
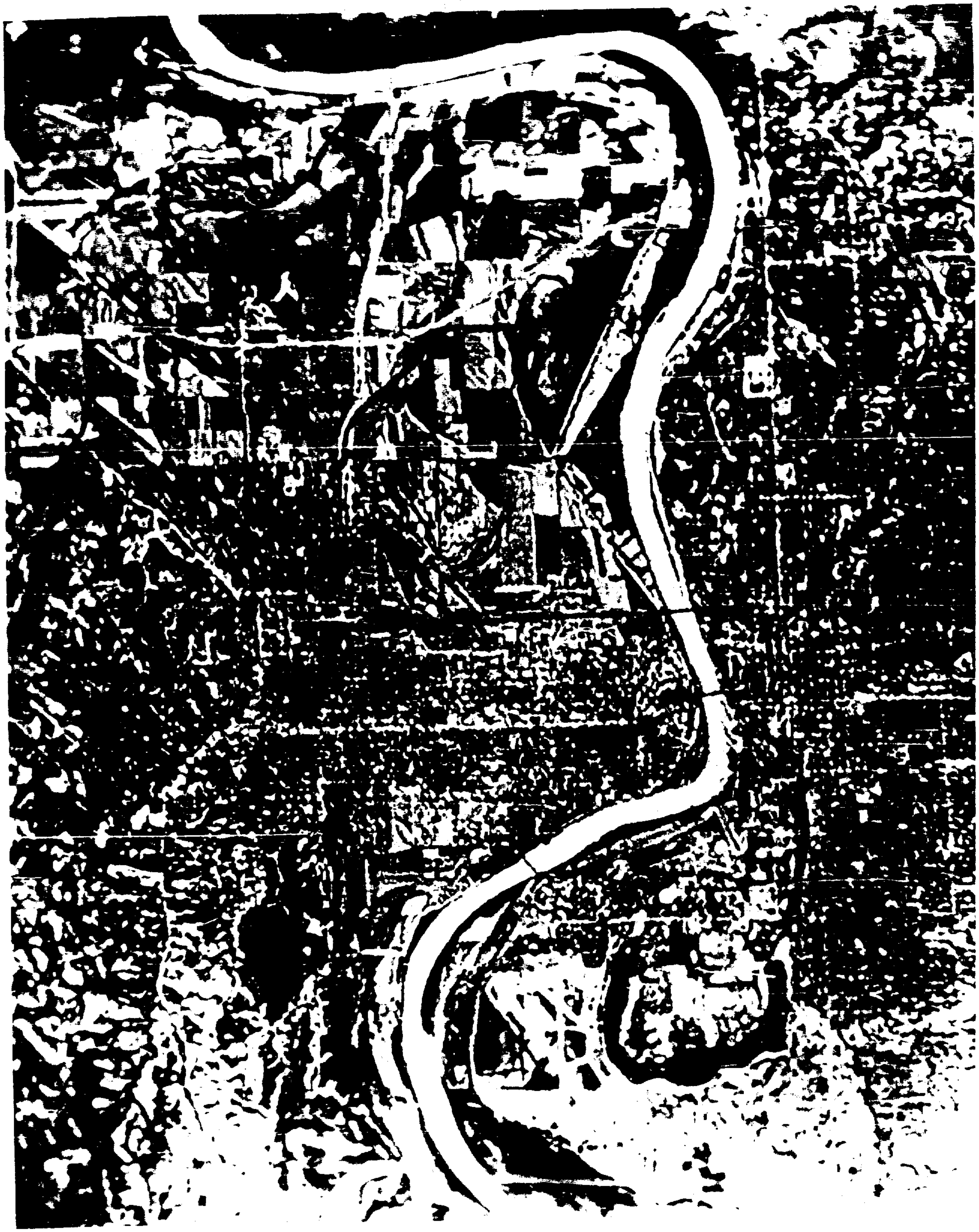


Fig. 6—Council Bluffs, Iowa, and Omaha, Nebraska (photocathode scale: 1:500,000)



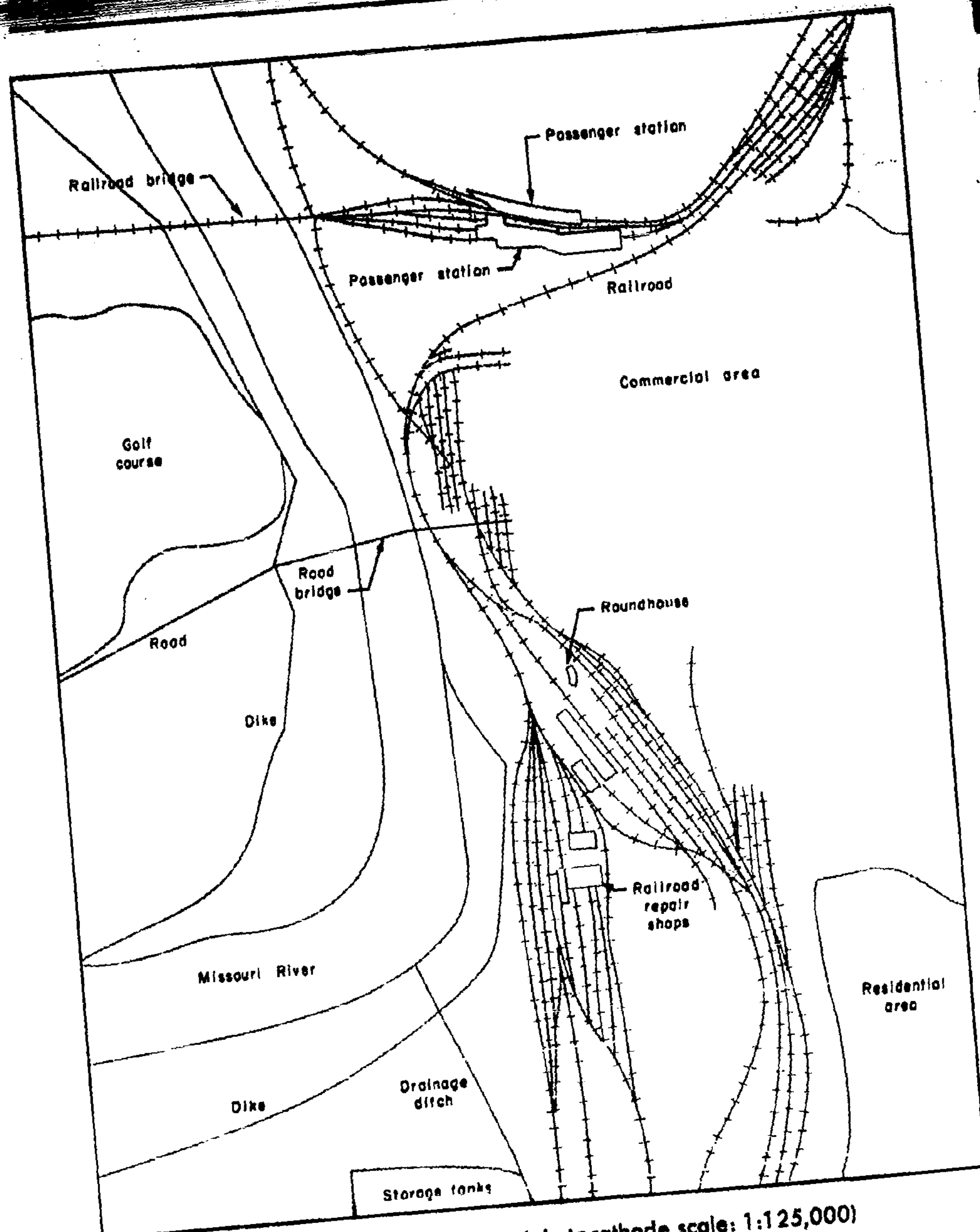


Fig. 7—Omaha, Nebraska (photocathode scale: 1:125,000)

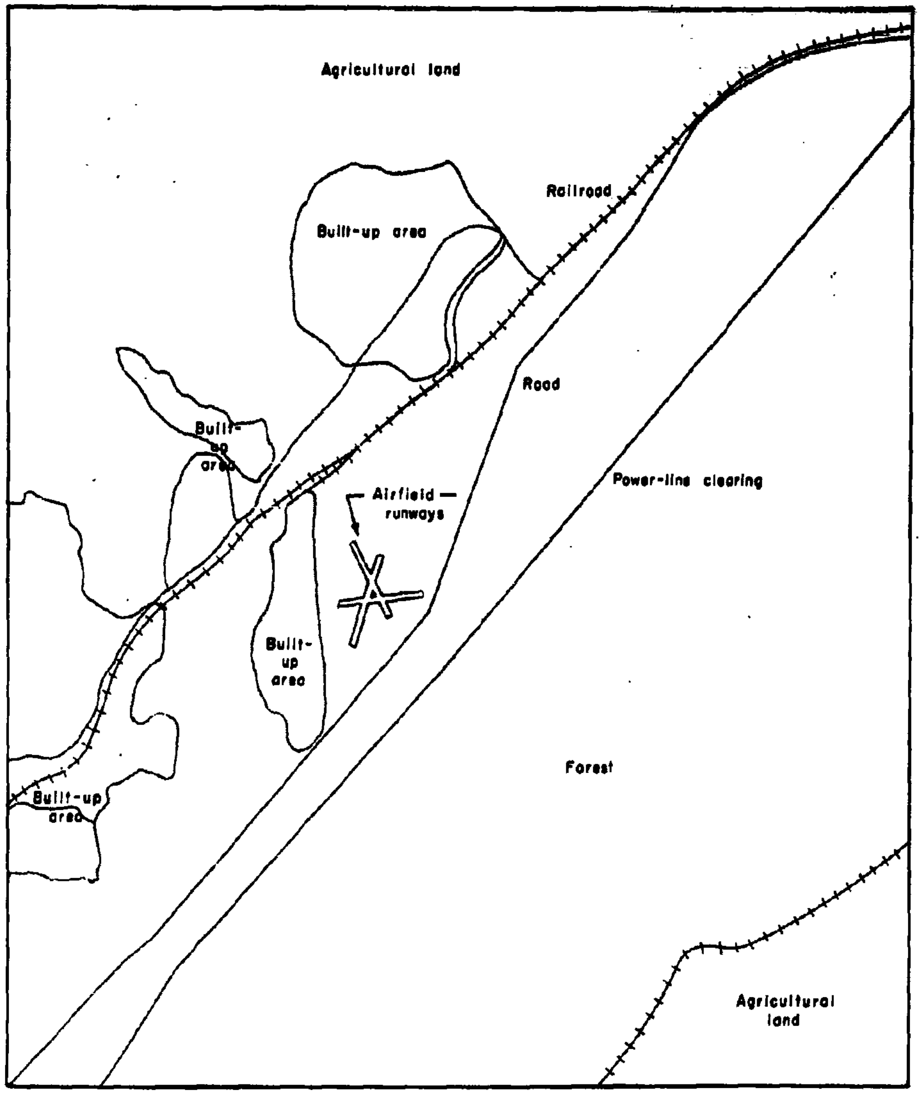


Fig. 8—Naval Air Station, Atlanta, Georgia (photocathode scale: 1:500,000)

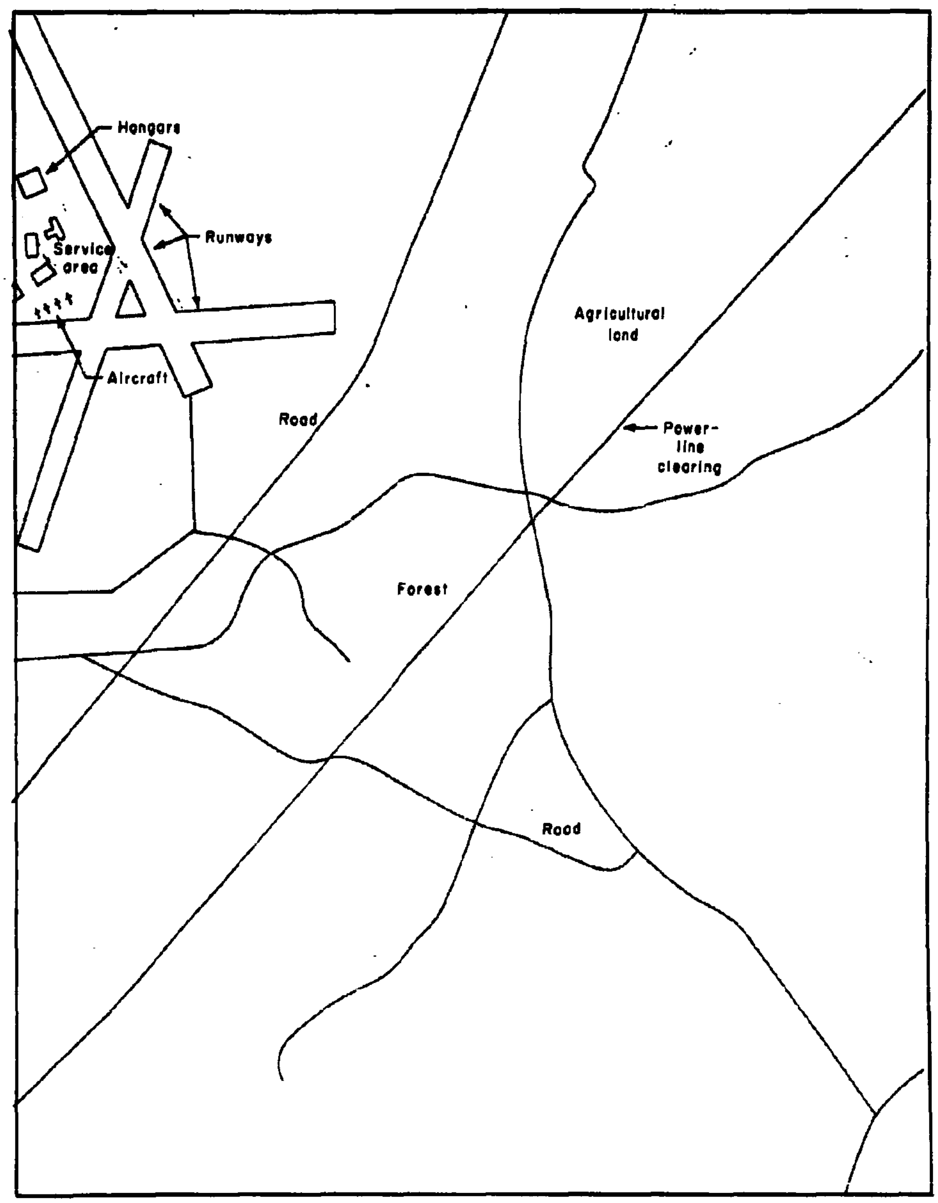


Fig. 9—Naval Air Station, Atlanta, Georgia (photocathode scale: 1:125,000)

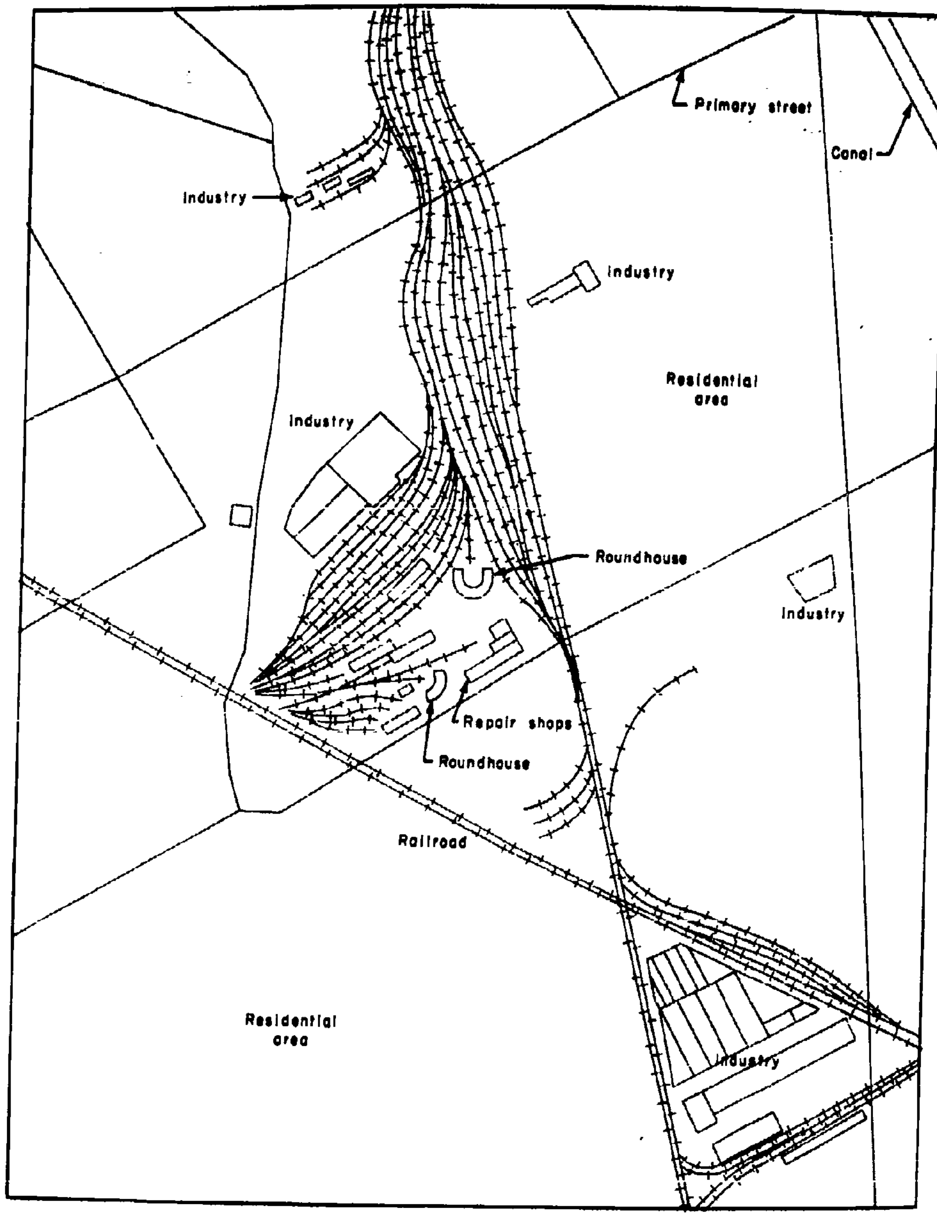


Fig. 10—Railroad yards and repair shops at Detroit, Michigan (photocathode scale: 1:125,000)

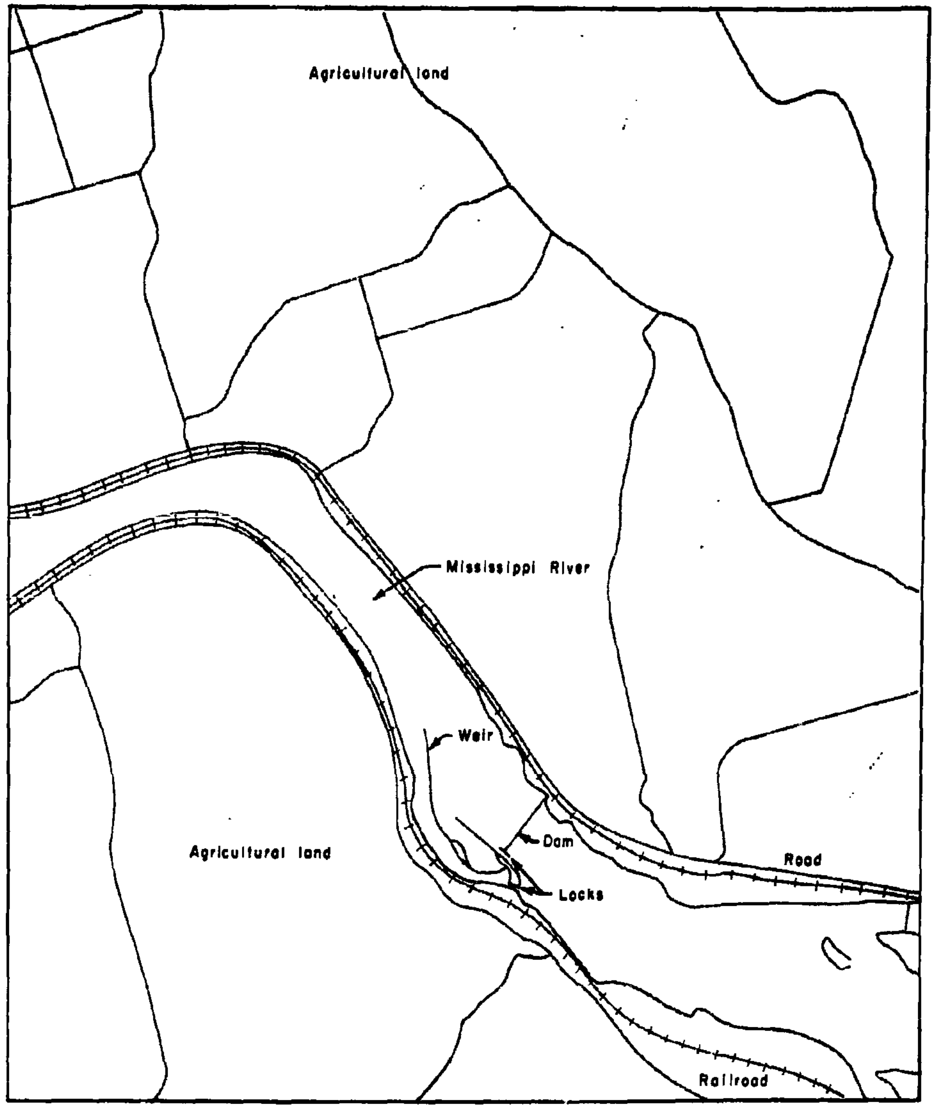


Fig. 11—Locks on the Mississippi River, northeast of Moline, Illinois (photocathode scale: 1:500,000)

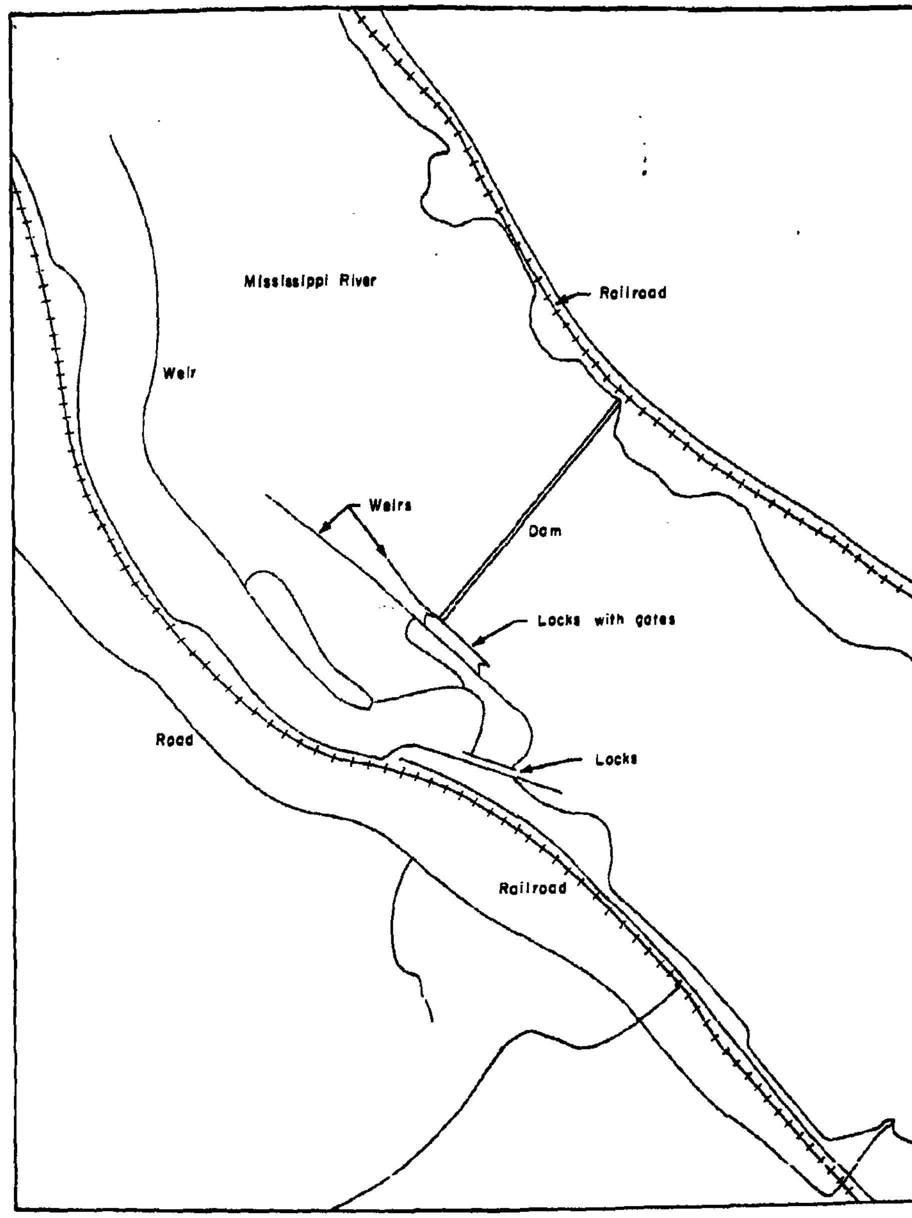


Fig. 12—Locks on the Mississippi River, northeast of Moline, Illinois (photocathode scale: 1:125,000)

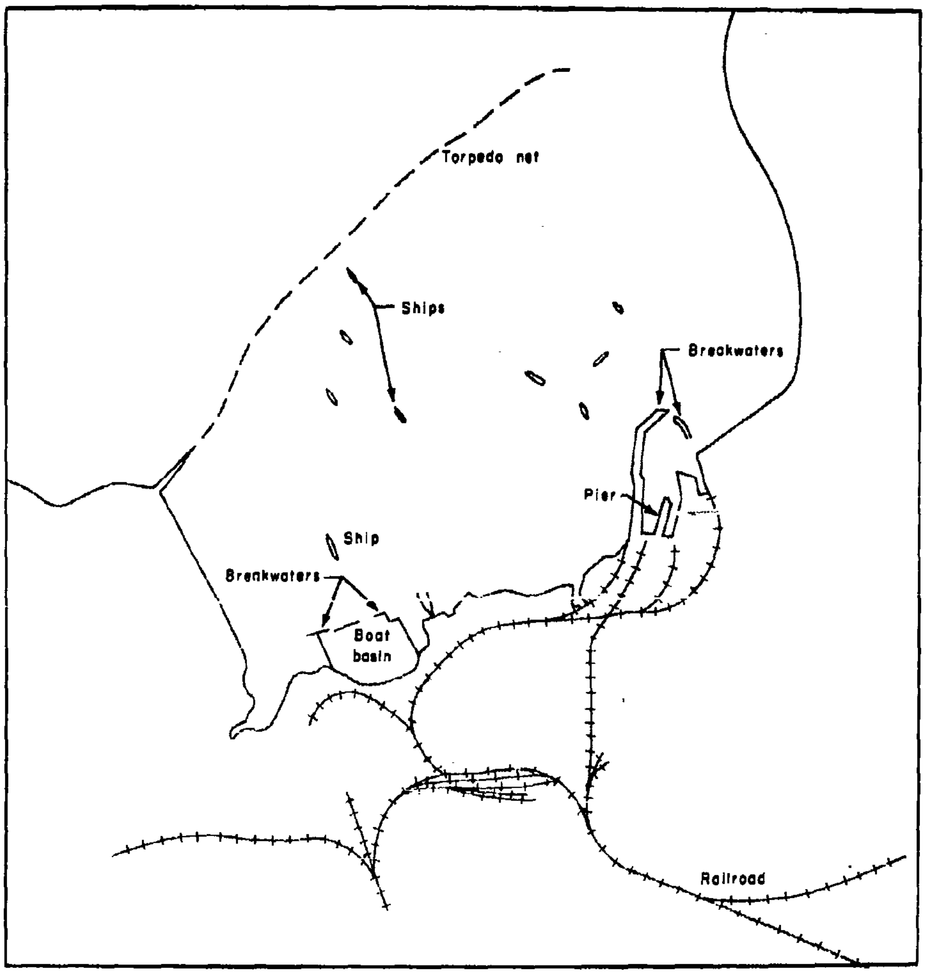


Fig. 13—Tallinn, Esthonia (photocathode scale: 1:500,000)

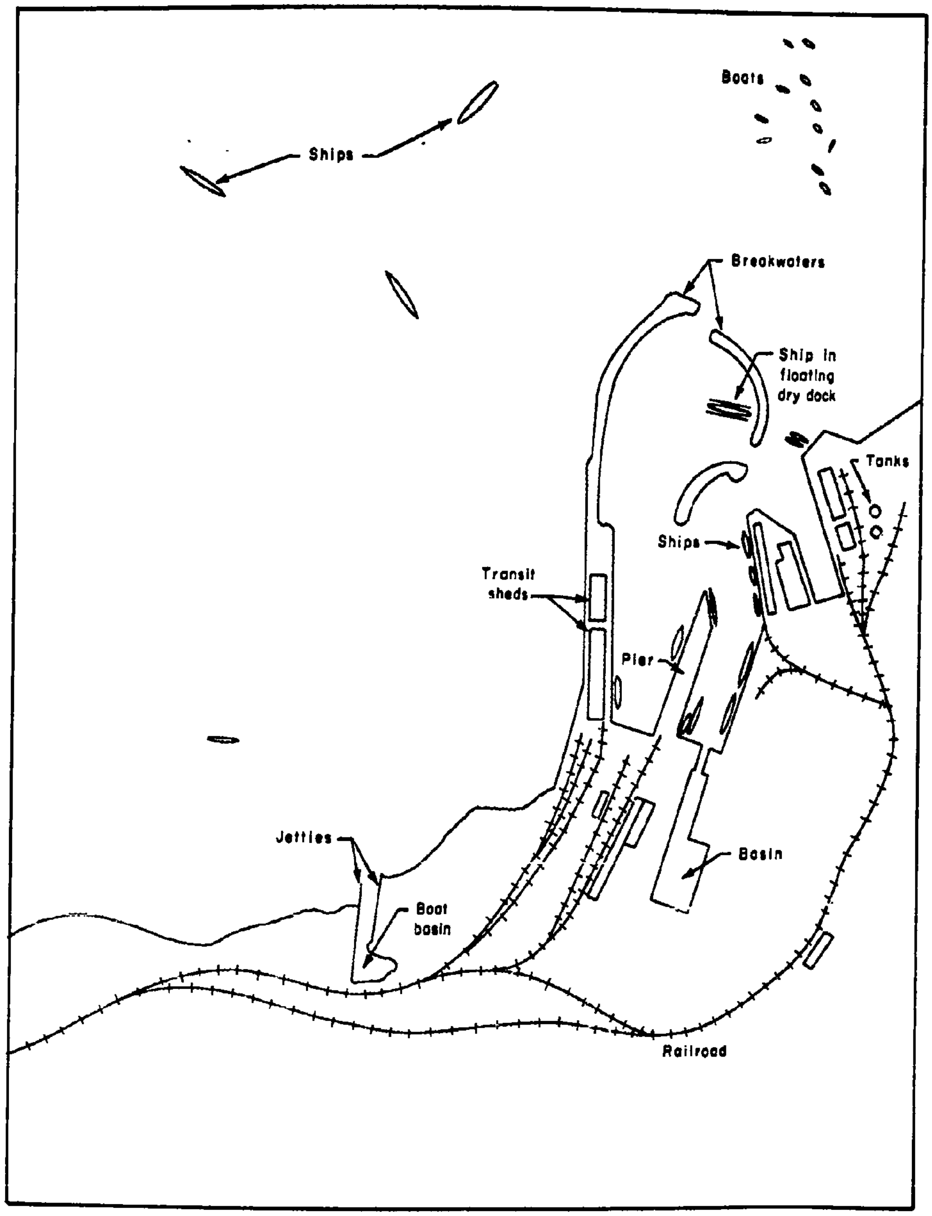


Fig. 14—Tallinn, Esthonia (photocathode scale: 1:125,000)

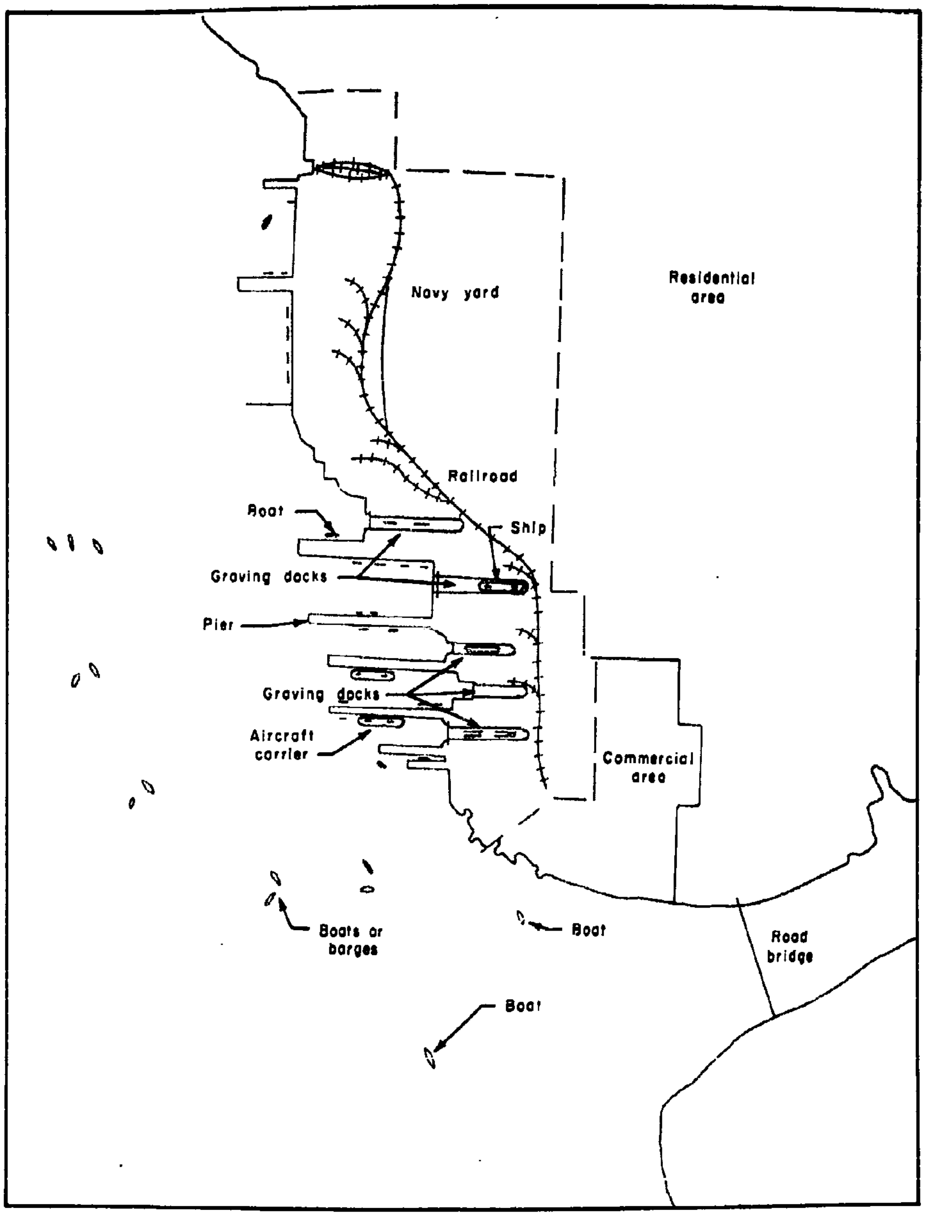


Fig. 15—Bremerton Navy Yard, Washington (photocathode scale: 1:125,000)

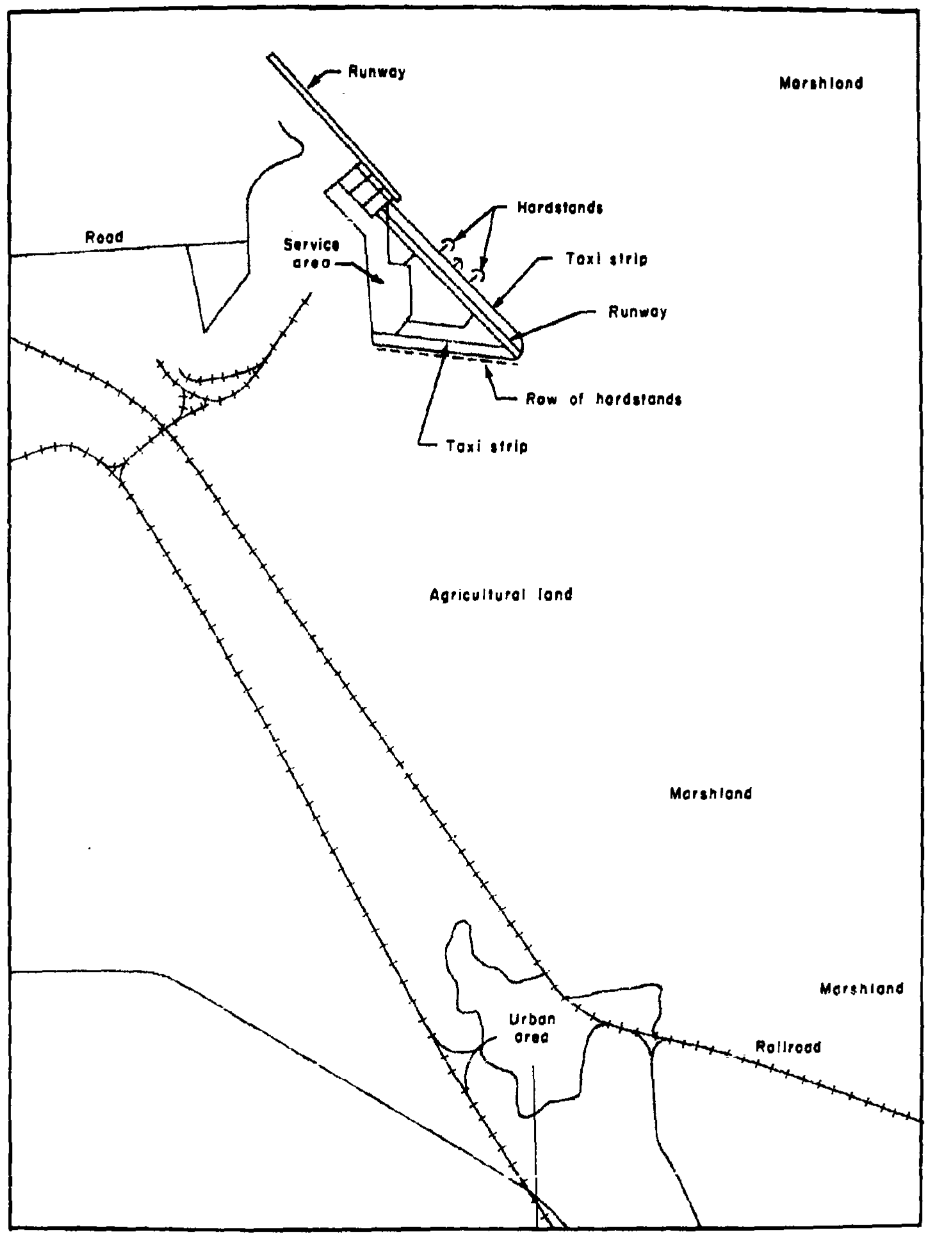


Fig. 16—Travis Air Force Base, California (photocathode scale: 1:500,000)

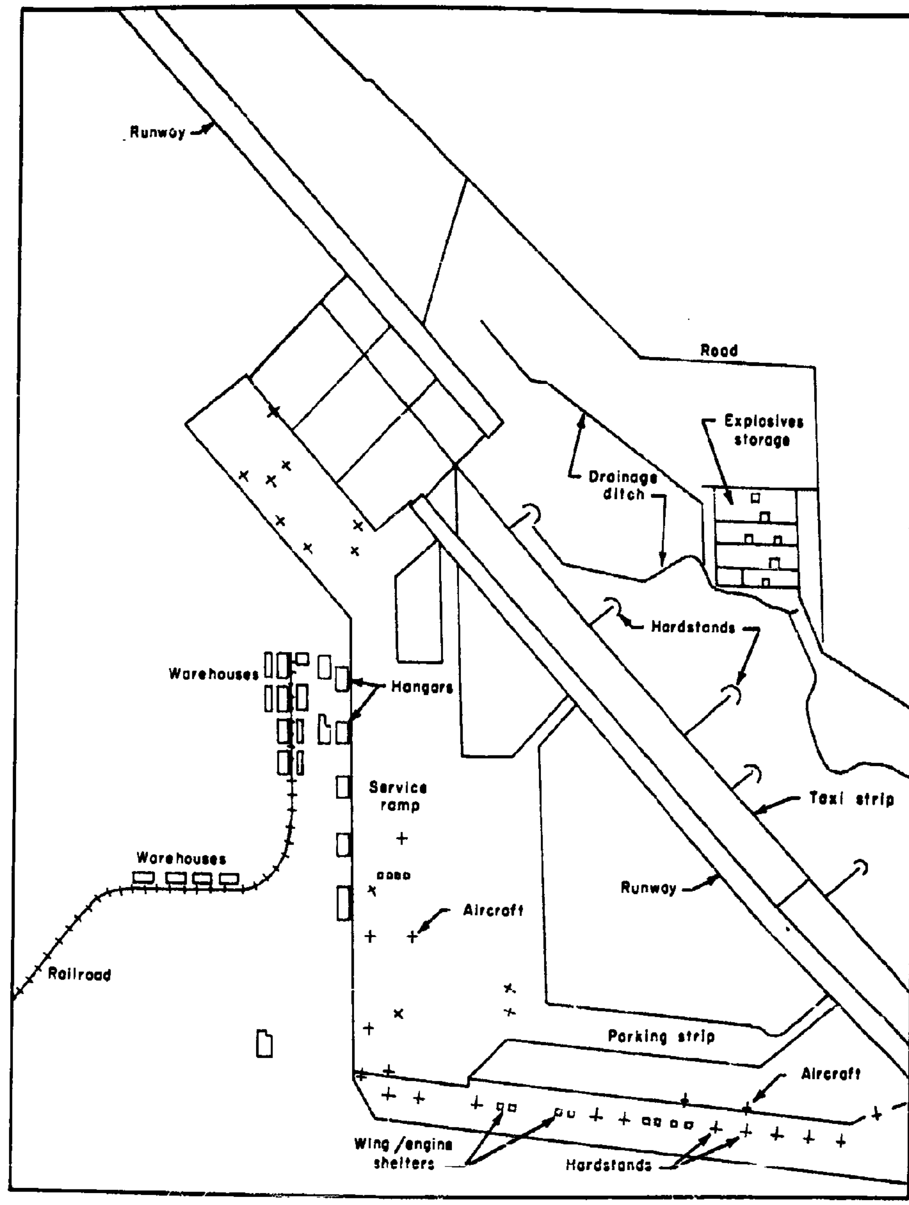
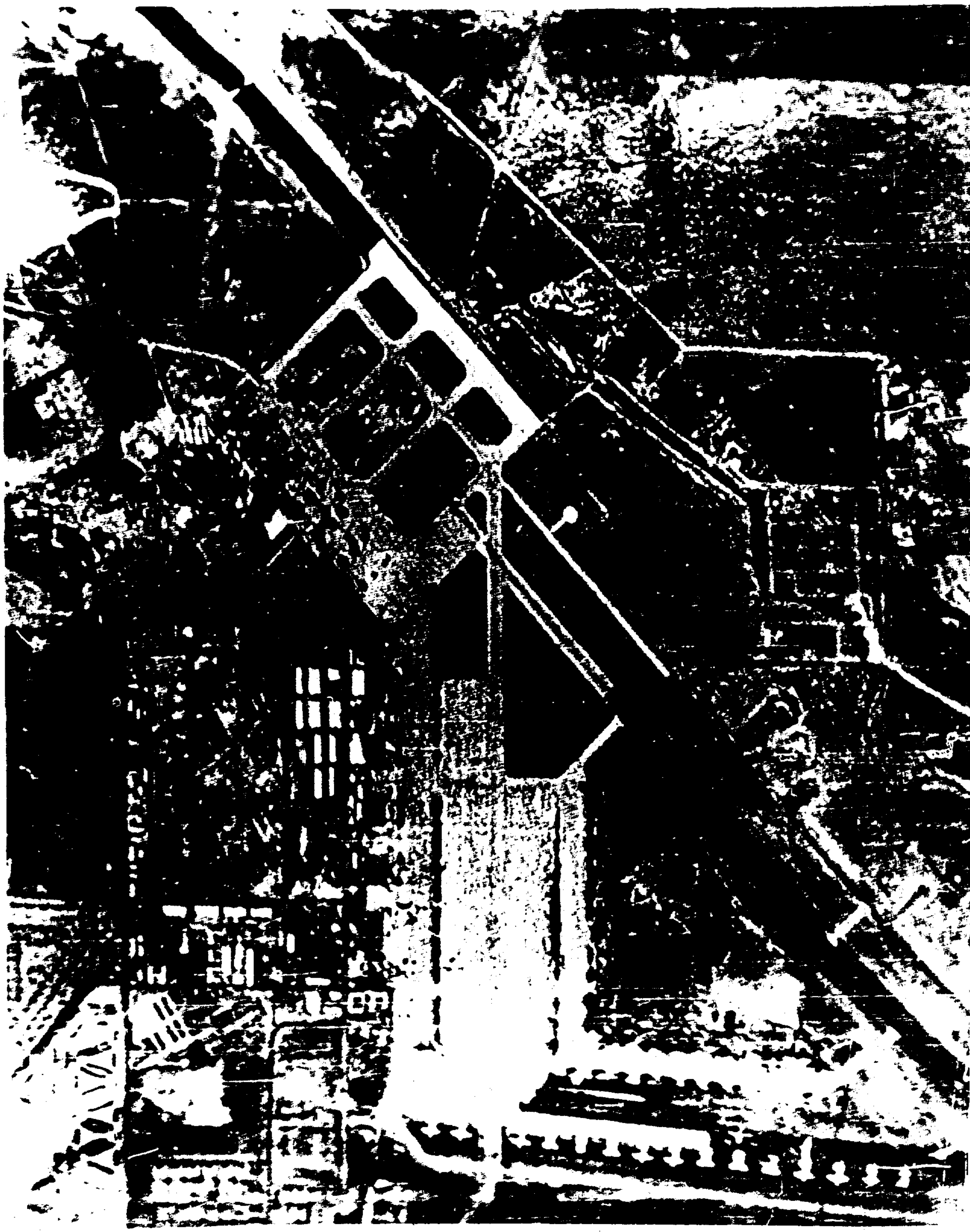


Fig. 17—Travis Air Force Base, California (photocathode scale: 1:125,000)



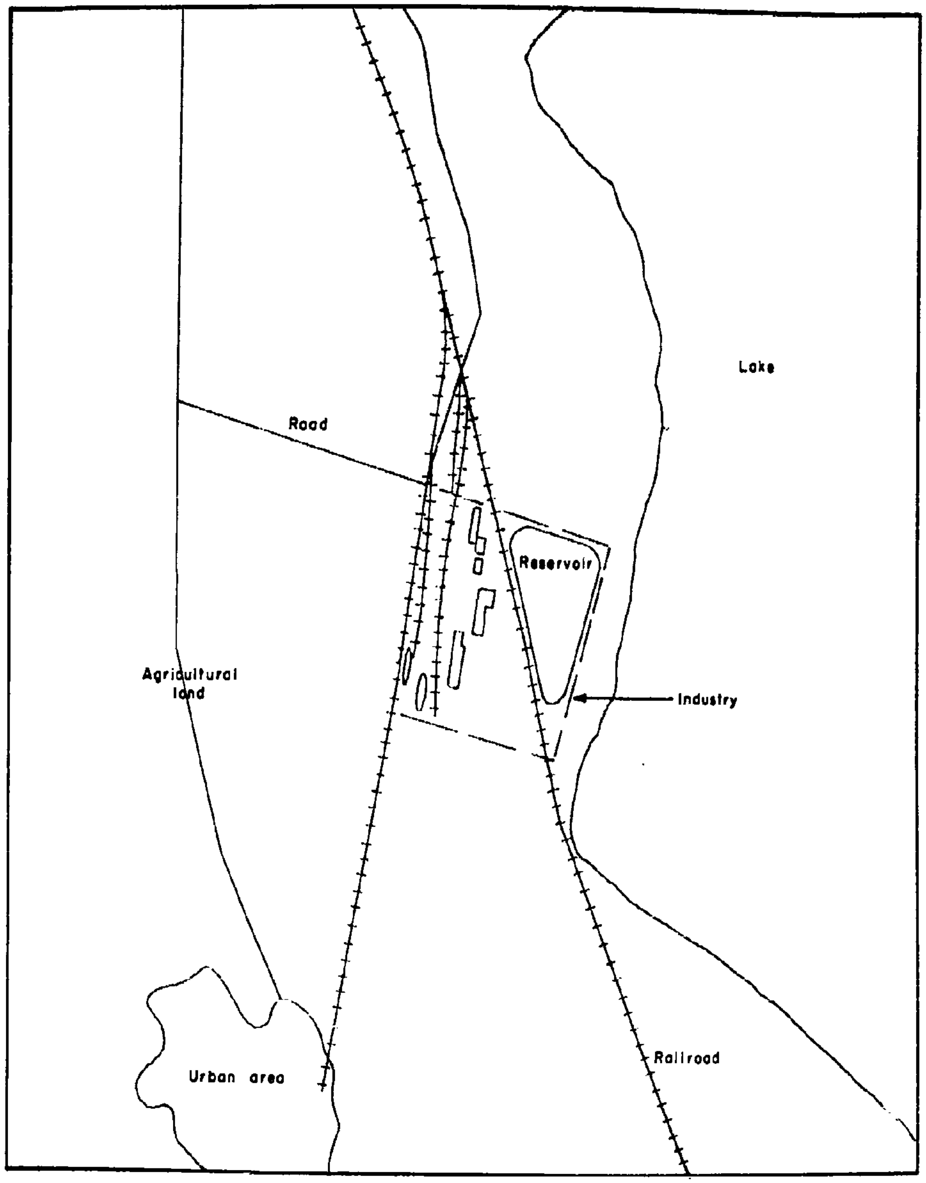


Fig. 18—Coke, iron, and steel plant at Provo, Utah (photocathode scale: 1:500,000)

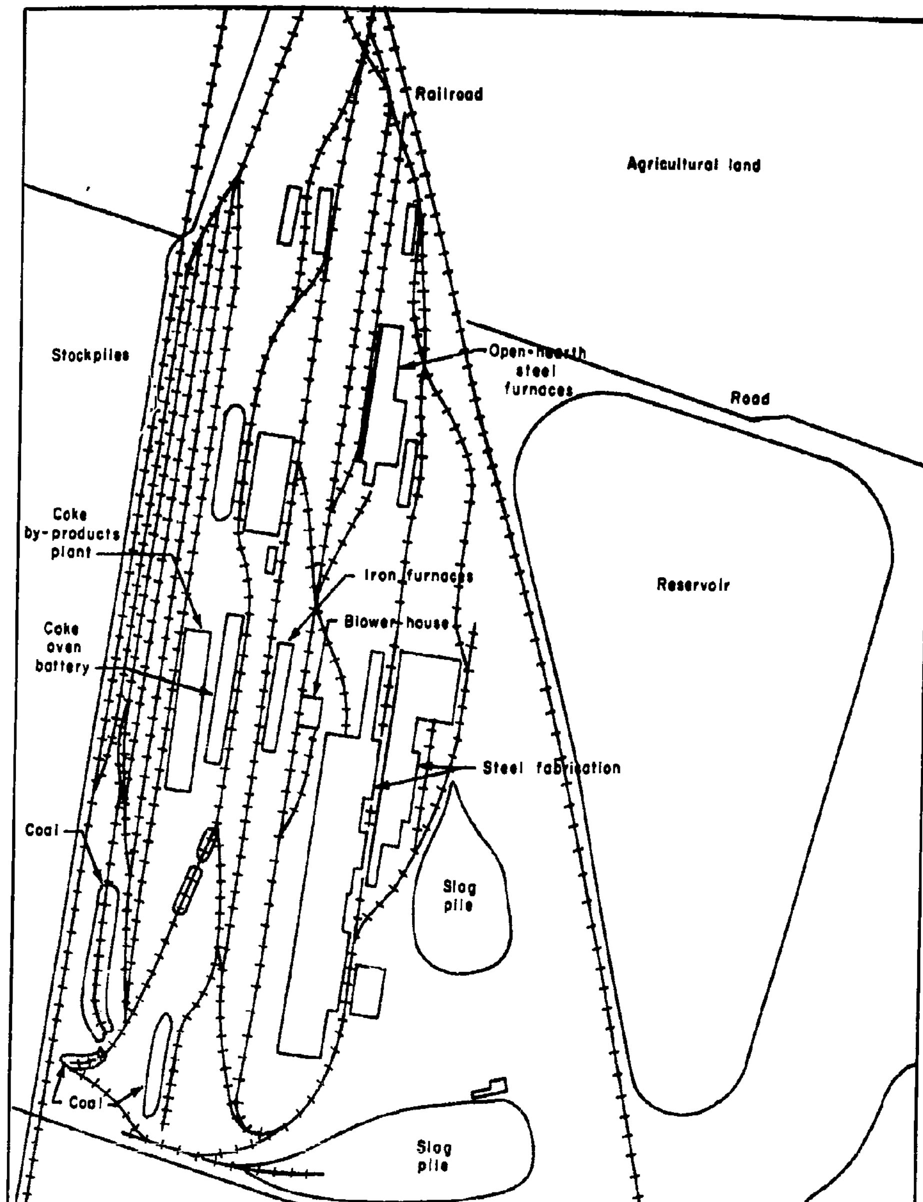


Fig. 19—Coke, iron, and steel plant at Provo, Utah
(photocathode scale: 1:125,000)

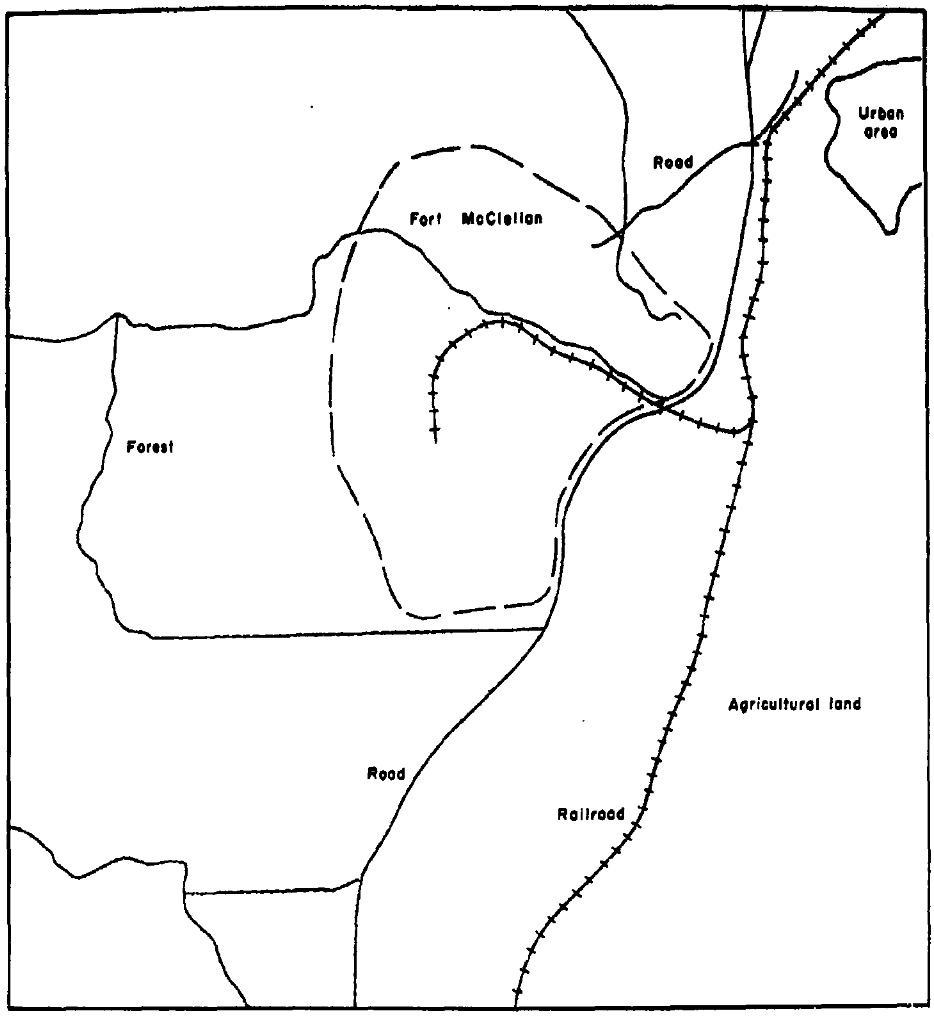
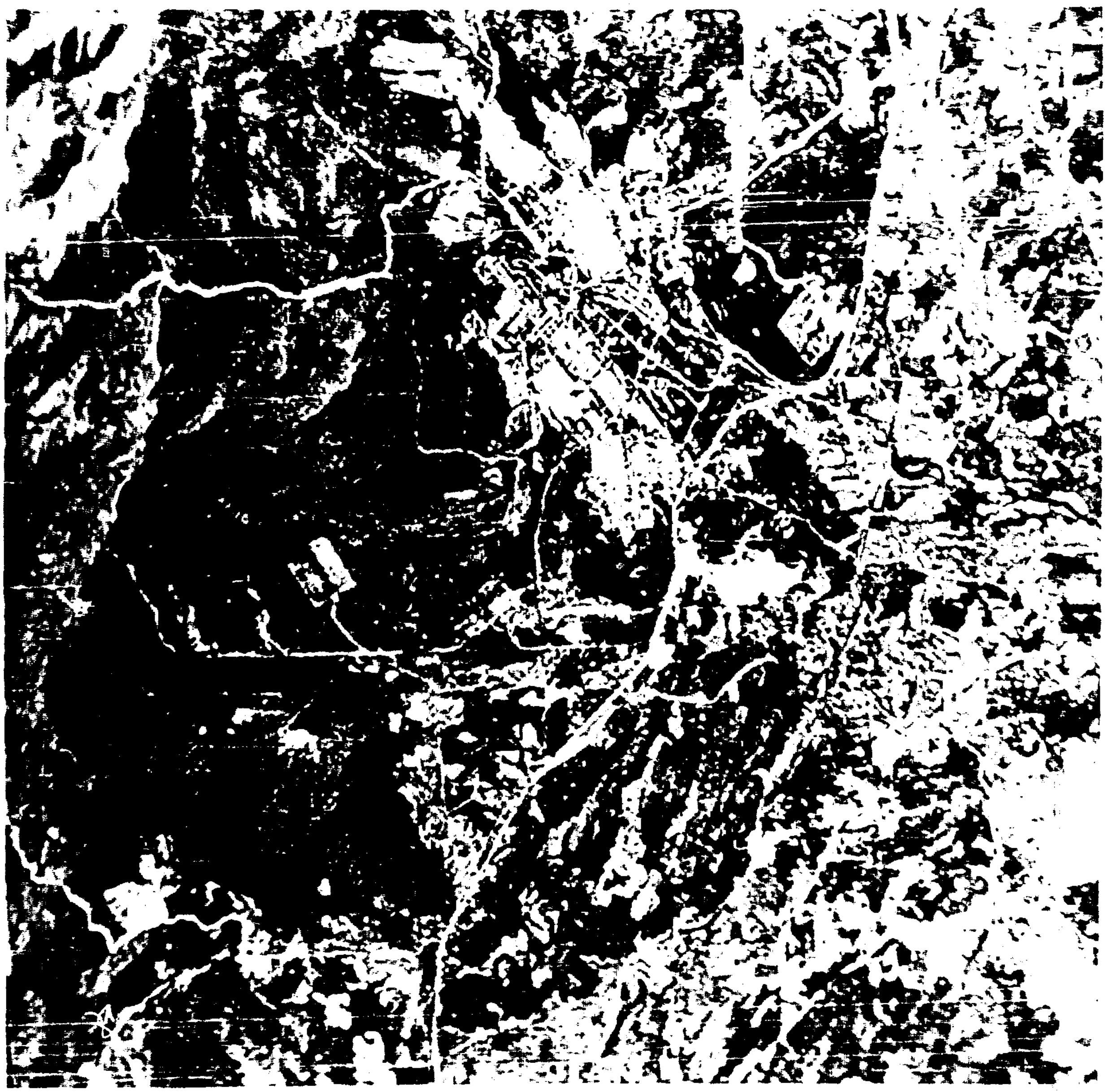


Fig. 20—Fort McClellan, Alabama (photocathode scale: 1:500,000)



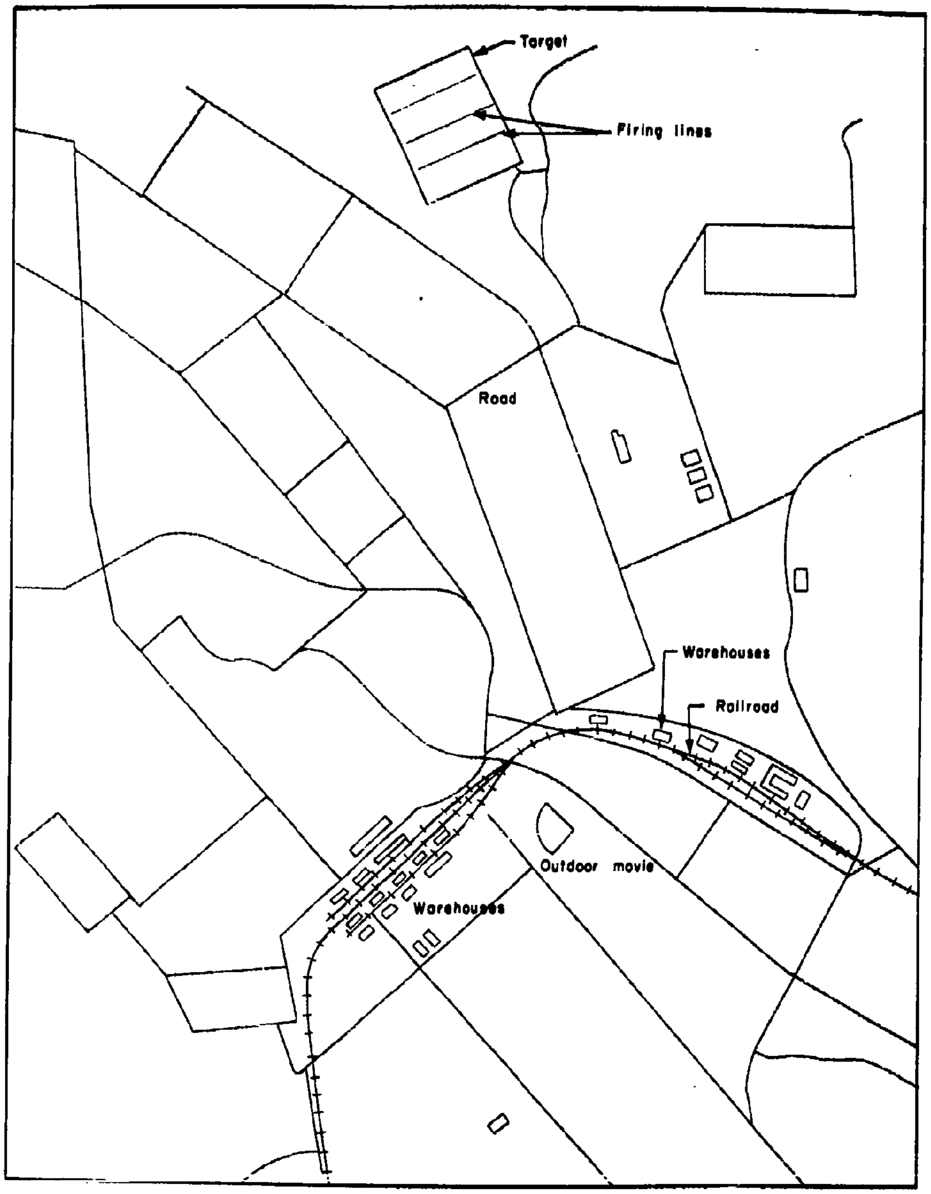


Fig. 21—Fort McClellan, Alabama (photocathode scale: 1:125,000)

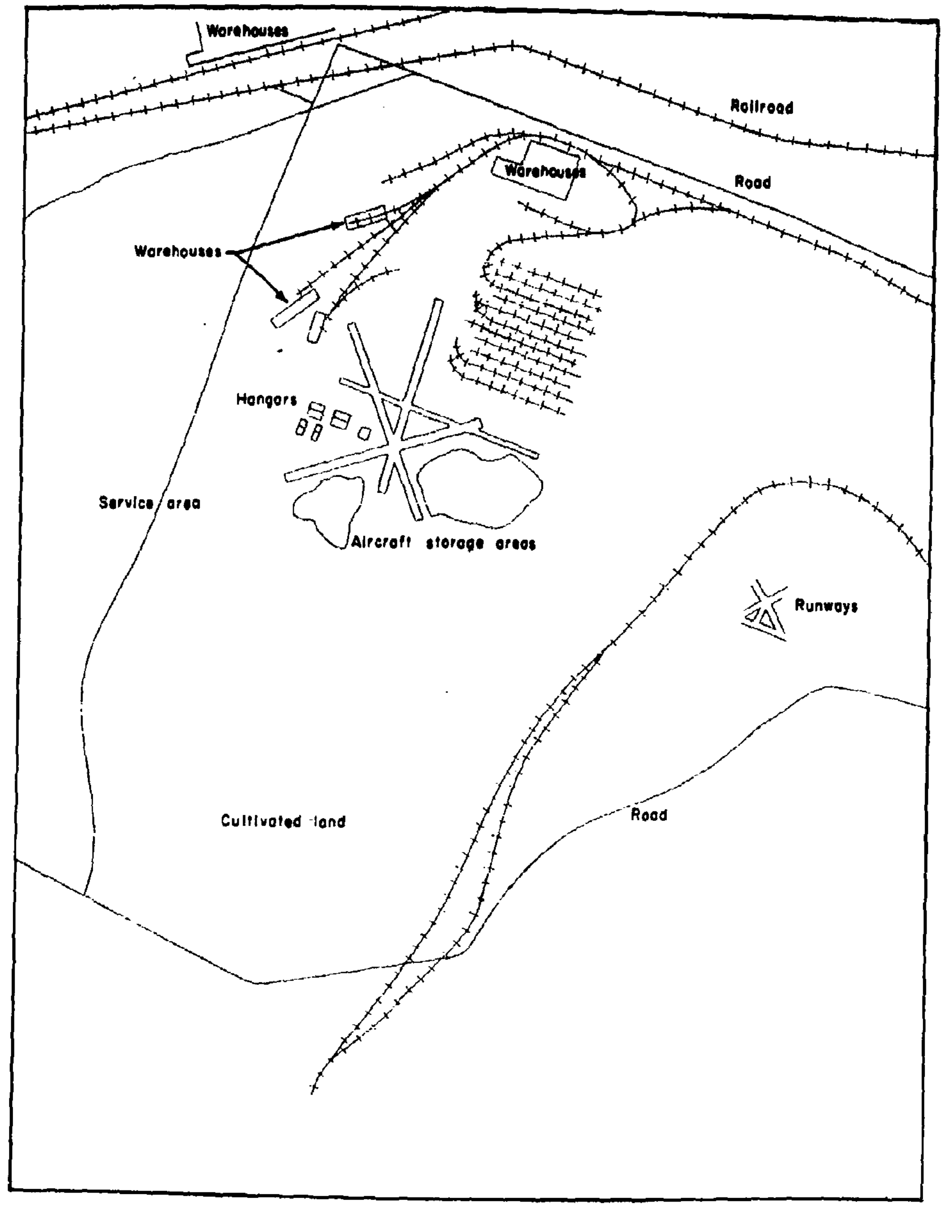
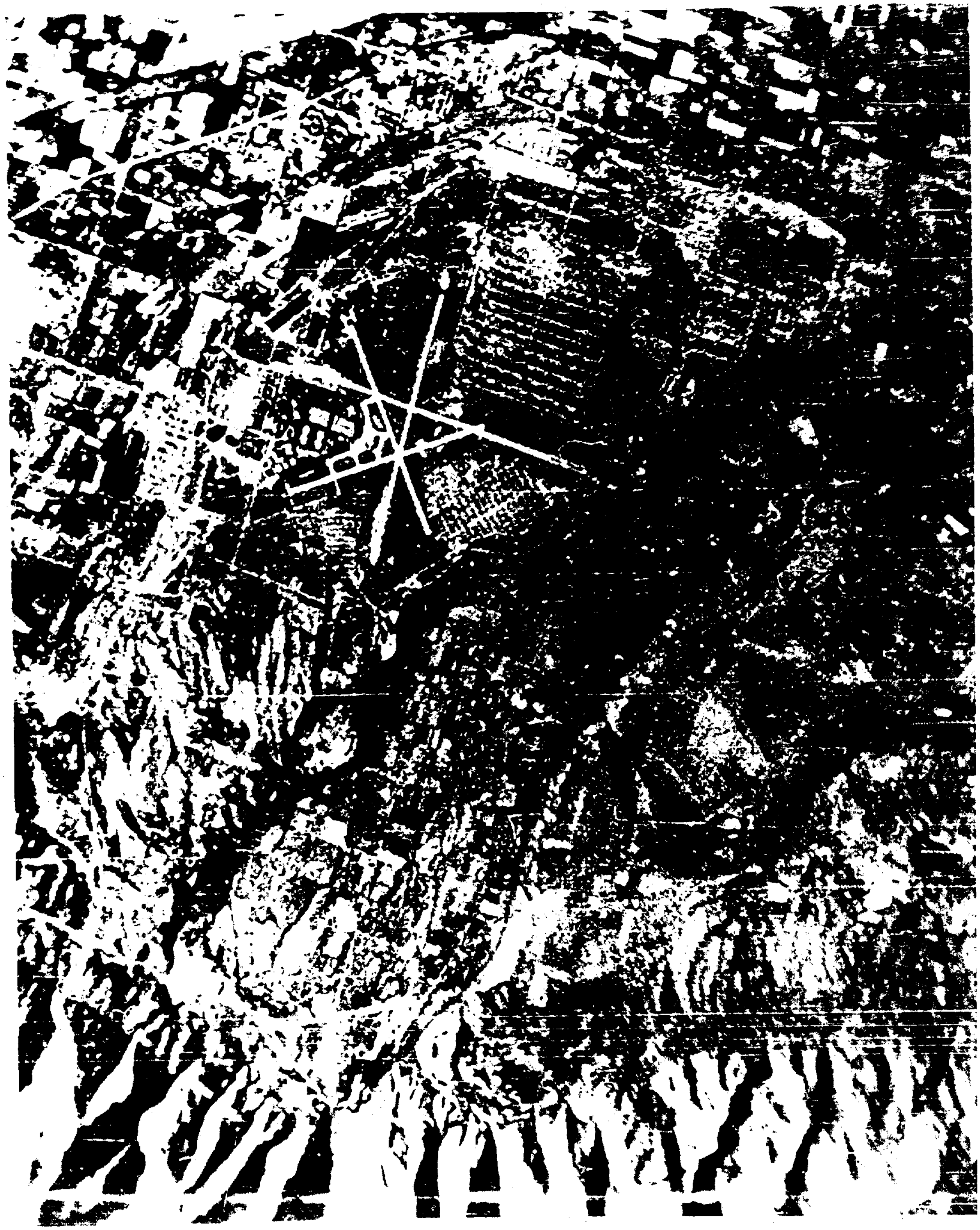


Fig. 22—Hill Air Force Base, Utah (photocathode scale: 1:500,000)



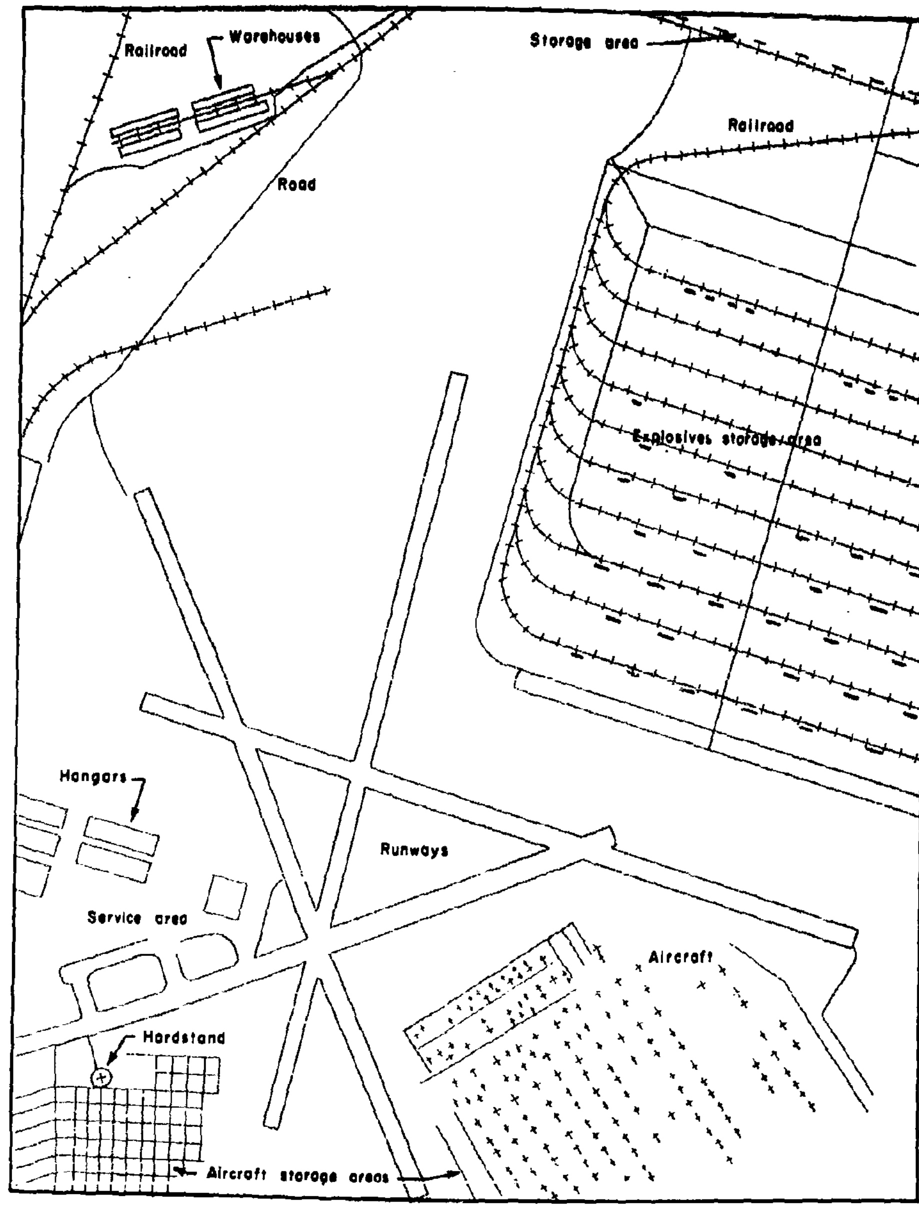


Fig. 23—Hill Air Force Base, Utah (photocathode scale: 1:125,000)

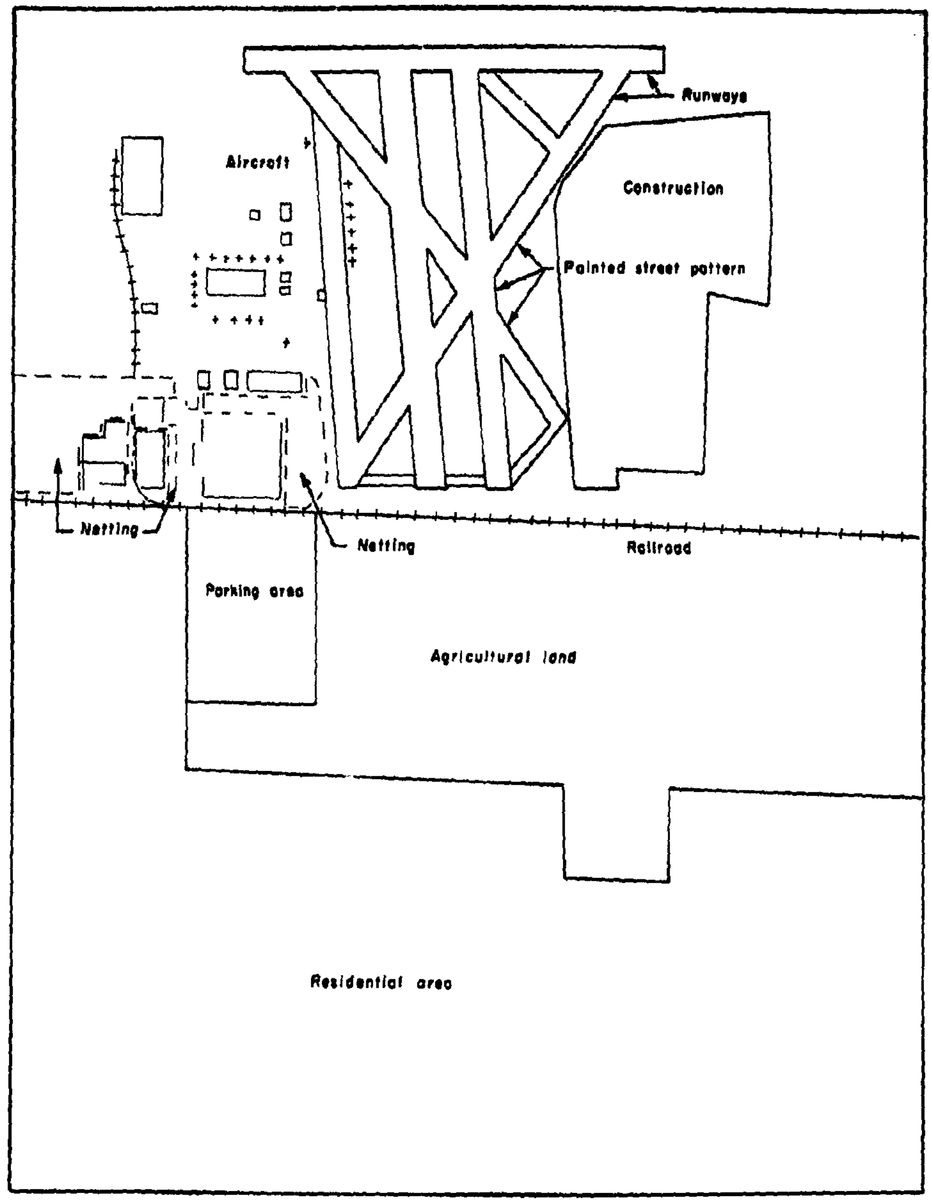
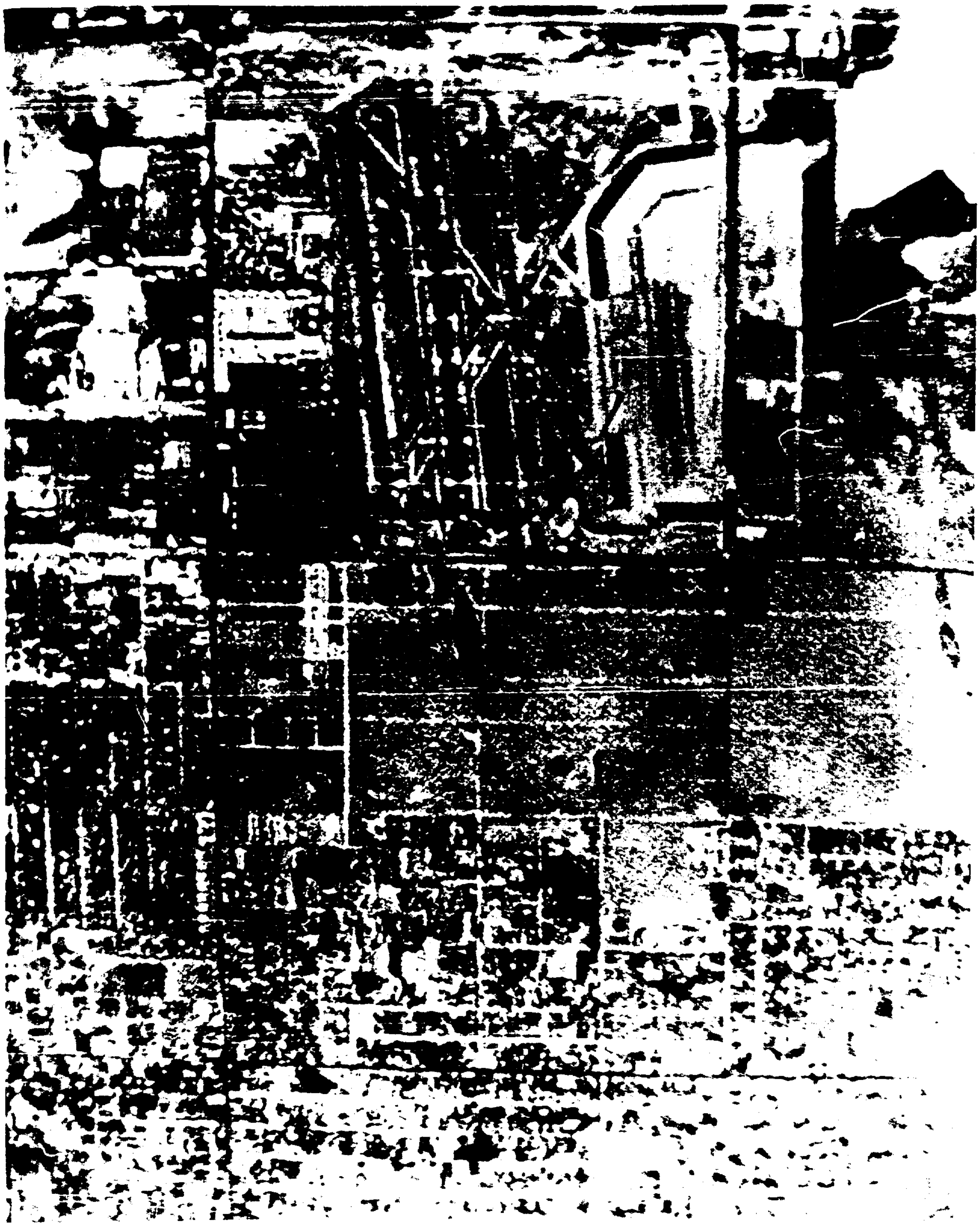


Fig. 24—Aircraft plant and Los Angeles International Airport, California (photocathode scale: 1:125,000)



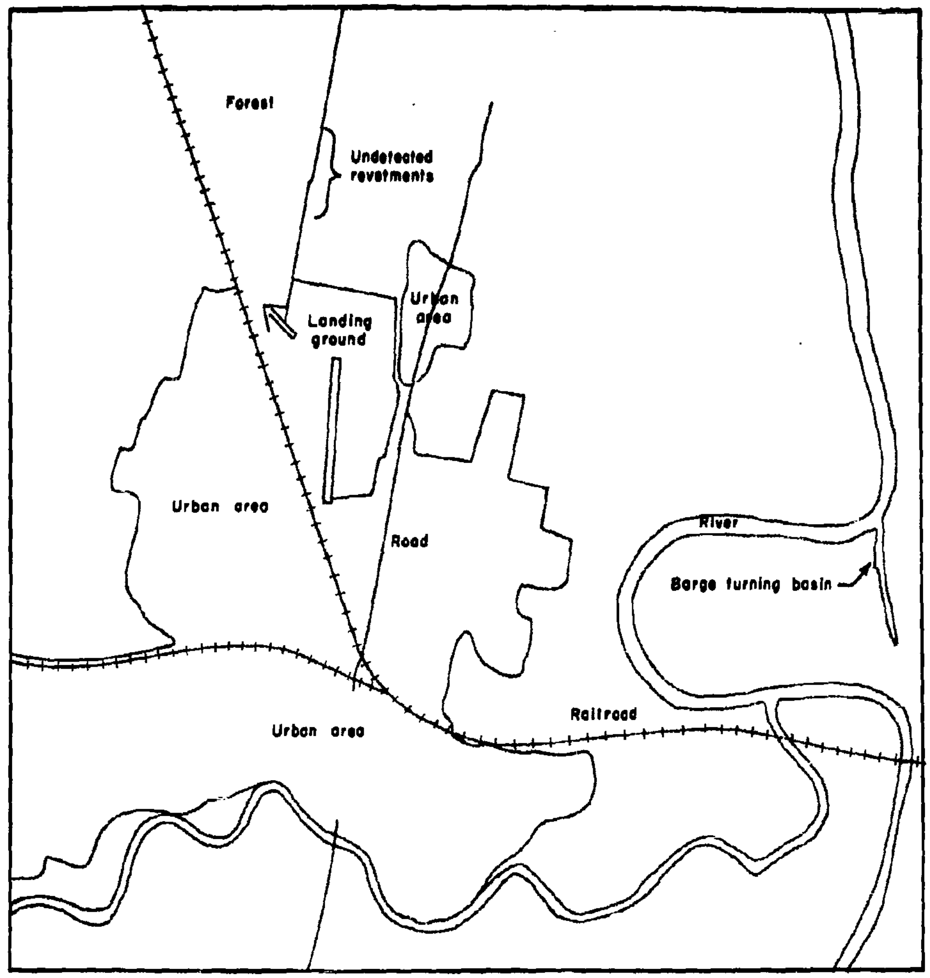


Fig. 25—Landing ground at Aken, Germany (photocathode scale: 1:500,000)

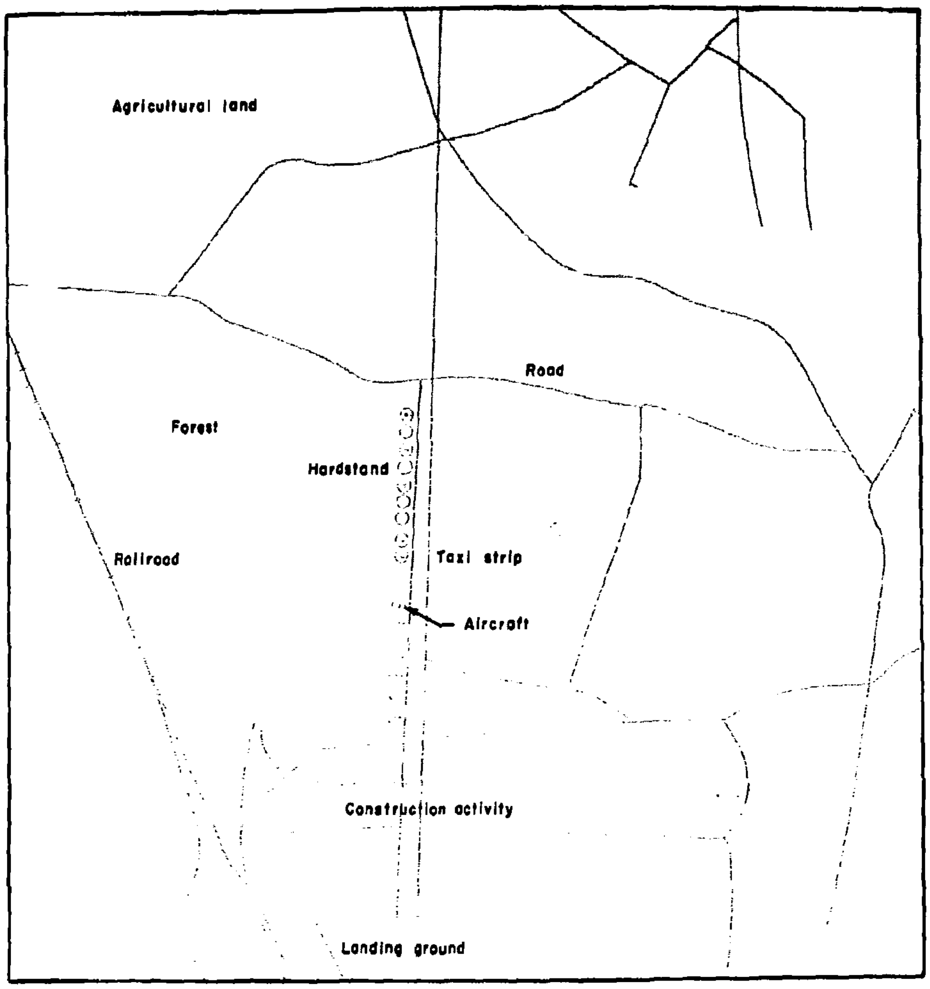


Fig. 26—Aircraft parking area at Aken, Germany (photocathode scale: 1:125,000)

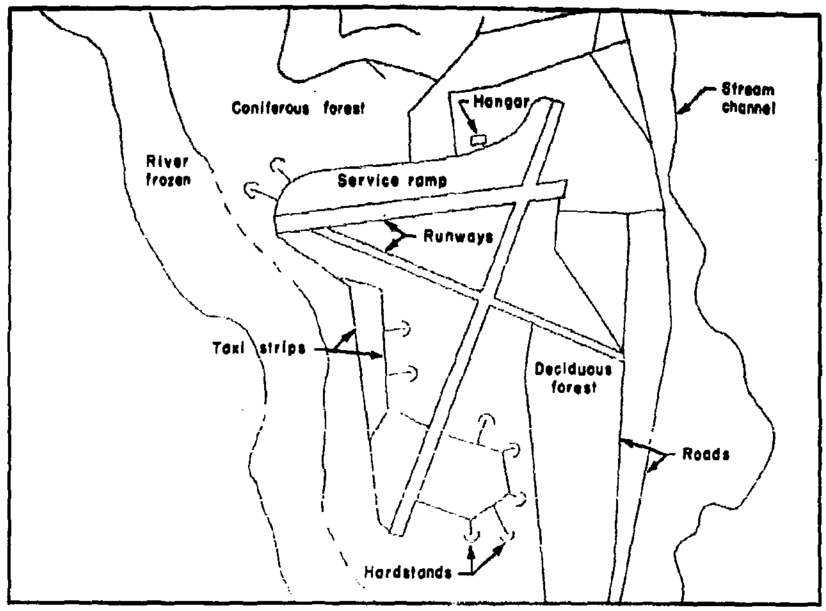


Fig. 27—Big Delta, Alaska (April 28, 1948; winter aspect)
(photocathode scale: 1:125,000)

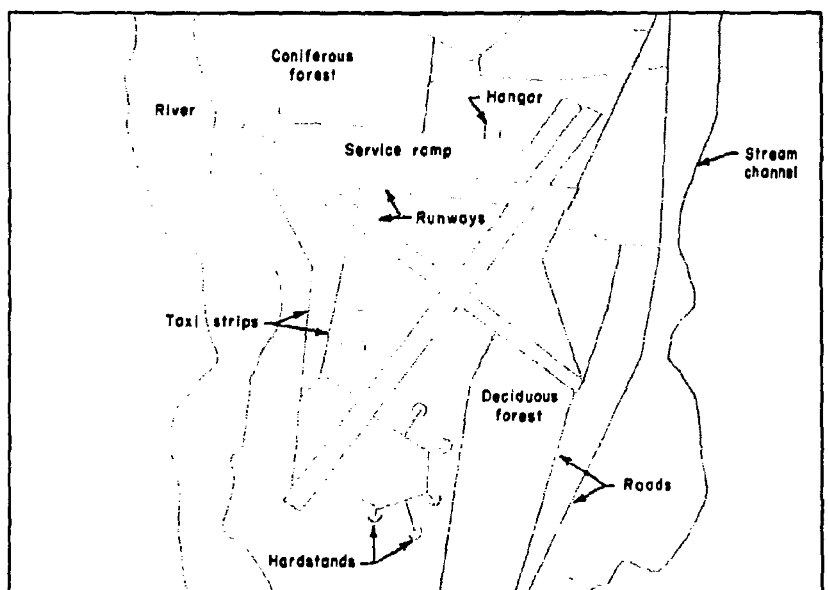
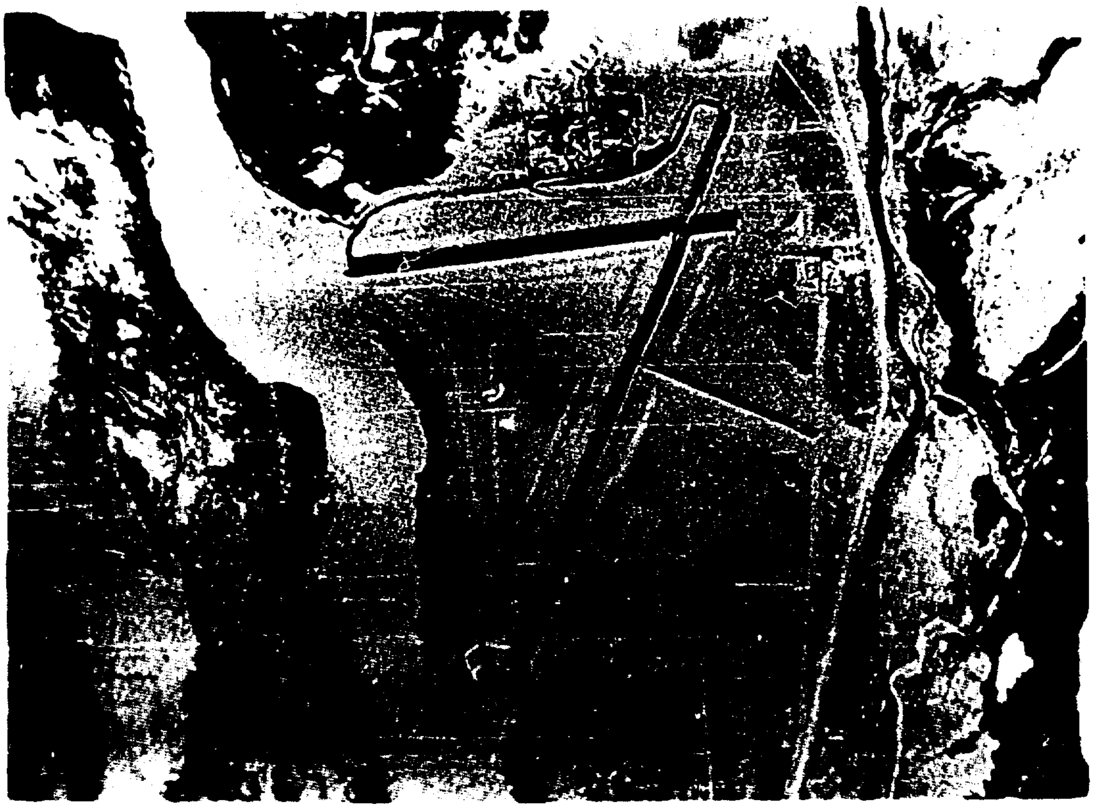


Fig. 28—Big Delta, Alaska (September 25, 1946; fall aspect, no snow)
(photocathode scale: 1:125,000)



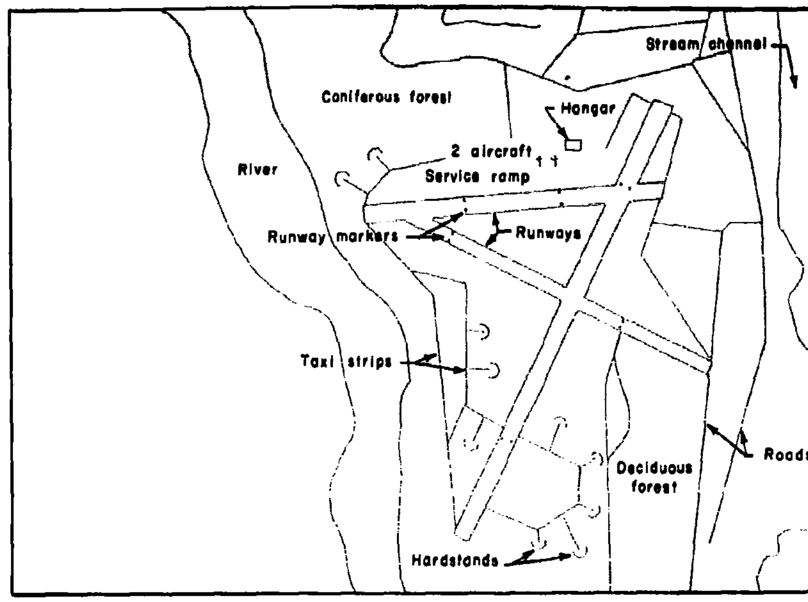


Fig. 29—Big Delta, Alaska (September 23, 1948; fall aspect, thin snow) (photocathode scale: 1:125,000)

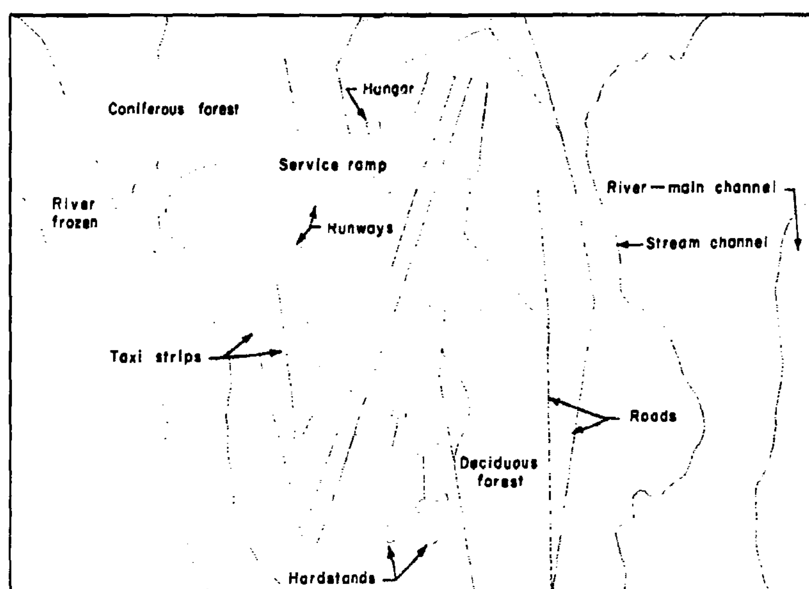
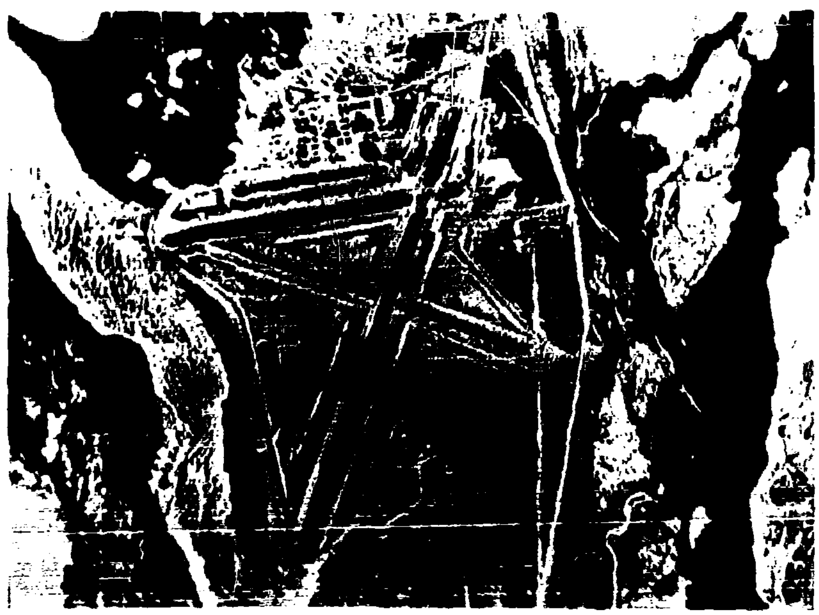


Fig. 30—Big Delta, Alaska (February 24, 1949; winter aspect) (photocathode scale: 1:125,000)



MAPPING INTELLIGENCE

A promising reconnaissance application of the satellite would be the accurate mapping of targets presently unknown as to existence or location. Although approximate location accompanies target identification as a primary goal of pioneer reconnaissance, mapping implies an accuracy comparable to that with which geodetic control points are located. By applying a checkpoint technique, such accuracy can be attained in the reduction of the satellite reconnaissance information.

This means that target locations can be found which are sufficiently close together to be useful for projected long-range guided missiles. For example, suppose that a checkpoint is used whose location is known to within 300 ft. Making certain conservative assumptions concerning the errors in the method, it can be shown that an unknown target location within 250 mi of the checkpoint can be established with a root mean square (RMS) error of about 720 ft.

The checkpoint method described here is not unique, but it is feasible and seems convenient in application. As the first step of the method, a relationship is established between the location of a point on the ground, the location of the vehicle, the attitude of the vehicle relative to a stable platform, and the attitude of the platform relative to the local vertical. Of these, the attitude of the vehicle relative to a stable platform can be measured directly. The attitude of the platform and the location of the vehicle may be found with the aid of data derived from prior and subsequent observations made by the television system of ground checkpoints. Because of low platform drift rate, it can be assumed that attitude remains virtually unchanged in the interval between checkpoint sightings. Accurate interpolation between checkpoints to ascertain vehicle location as a function of time is enhanced by the prior determination of the elements of the orbit.

If the interpolation interval is selected to cover a time when the vehicle sees the target whose location is desired, the above-mentioned basic relationship can be solved for the unknown target location.

When an error analysis is performed on this method, the following sources of error are found:

1. Imperfect knowledge of checkpoint location.
2. Resolution of optical system.
3. Optical and mechanical imperfections of scanning system.
4. Gimbal angle pick-offs.
5. Stable-platform drift.

6. Imperfect knowledge of orbital inclination and period.
7. Lack of knowledge of target altitude.
8. Altitude changes of vehicle.

Of these, item (1) is inherent in the checkpoint method and items (2), (3), and (4) are inherent in the construction of the attitude-sensing and information-gathering systems. The corresponding errors cannot be reduced except by a multiple checkpoint method or an improvement in the design of the system components. Items (5) and (6) lead to errors which are proportional to the distance traveled (or time elapsed) between the sightings of checkpoint and target. Therefore, these errors can be reduced by using checkpoints as close as possible to the unknown target location. Items (7) and (8) give errors which are proportional to the tangent of the angle between the line of sight to the target and the nadir direction from the vehicle. By restricting the use of the method to targets almost directly below the vehicle, these errors can be kept small. Finally, the errors from items (3), (4), and (5) are almost directly proportional to the orbital altitude.

The magnitudes of the errors arising from several of the sources can be estimated only crudely at the present time. In particular, those which depend on the physical construction of the scanner and attitude-sensing system may be subject to considerable revision. Those which depend on a knowledge of the elements of the orbit may vary according to the observation scheme used to deduce these elements.

An error summary is given in Table 1, page 72, under the basic assumptions that—

1. The orbital altitude is 300 mi.
2. The distance between checkpoint and target is 250 mi.
3. The checkpoint and target lie in a strip no more than 20 mi (two 10-mi-square frames) to either side of the track of the satellite trajectory over the earth.

The third restriction not only reduces the effect of altitude variations, but also virtually eliminates errors caused by yaw variations. Therefore, the effects of sources (3), (4), and (5) of the table have been computed on the basis of roll and pitch attitude errors only.

The expected RMS error in target location is seen to be 720 ft. Note that if the target and checkpoint lie directly under the vehicle, the total RMS error is reduced to 630 ft. Furthermore, if the elements of the orbit are known perfectly and if there is no platform drift, the total RMS error is reduced to 550 ft.

Table 1

Source	Assumed RMS error of source	Contribution to RMS error in target location
1. Checkpoint location	300 ft	300 ft
2. Resolution	100 ft	100 ft
3. System optical and mechanical imperfections	30 in. (each attitude)	320 ft
4. Gimbal angle pick-offs	30 in. (each attitude)	320 ft
5. Stable platform drift	0.02 deg/hr	negligible
6. Orbital inclination	1 ft	270 ft
7. Orbital period	1 part in 10^4	130 ft
8. Altitude variations	1 mi (vehicle) 500 ft (target)	350 ft
	Total RMS Error = 720 ft	

It does not seem likely that the construction errors of the scanning and sensing systems can be reduced drastically without making them considerably more elaborate than is presently planned. Therefore, an RMS target-location error of about 550 ft seems to be the practical minimum attainable.

In evaluating the results of the analysis, it must be kept in mind that all depends on the existence of suitable checkpoints. This means that the checkpoint location itself must be known closely, it must lie nearly under the satellite when the latter passes near the unknown target location, and it must be located sufficiently close to the target. The numbers assumed for the checkpoint location and removal from the target may be typical for southwestern USSR. However, a much worse condition exists over most of the USSR. In Siberia, particularly, checkpoint positions may be known only to the order obtainable from astronomical observations without triangulation—e.g., of the order of 1 mi. Their removal from the target may also be considerably more than 250 mi.

It is probable that, with statistical smoothing afforded by repeated passes from continuous operation of the satellite and with the use of multiple checkpoints, any unknown target may eventually be located to within less than one-tenth of a mile. This would then constitute a mapping capability within the requirements of the operational long-range bombing systems extant in the period of Feed Back usefulness.

It is believed that radar maps can be synthesized from pictures. Map-matching Atran-type guidance to any point in Russia would thus be materially enhanced by such an expedient.

WEATHER INTELLIGENCE

A necessary part of any aerial mission is a knowledge of meteorological conditions along the flight path for both manned and unmanned vehicles. It can be assumed that, in the event of armed conflict, weather reconnaissance such as was performed in World War II would not be available because of the deep penetrations involved. The question then arises: How can information be obtained that is needed to augment knowledge of peripheral weather? One answer may be the use of the satellite for weather reconnaissance, a possibility that has been treated in some detail in a previous RAND report.[16] Although quantitative data on temperatures and pressures do not appear as being likely products of the satellite reconnaissance, it does seem possible to obtain some intelligence on the synoptic weather situation over Russia. Specifically, an analysis of rocket photographs shows that there is a possibility of determining direction of temperature gradient, areas of convergence, wind shear and direction, and, in special cases, pressure tendency. We should note that, although the study showed an analysis of this type to be possible, there are many difficult problems to be solved, and research would be necessary to demonstrate the value of the procedure.

One feature, however, appears certain: Given day-to-day continuity of pictures over a large area, storm systems could be traced and large-scale changes could be noted. With this in mind, let us examine the coverage and continuity that might be expected from the satellite system as it is visualized at present.

Coverage and Continuity

Let us assume that one type of information that can be obtained from the satellite is cloud coverage. Further, if we accept the fact that the locations of low-pressure cyclonic systems are indicated by their associated clouds, then it should be possible to examine the probability of detecting this type of weather situation from satellite pictures.

To do this we shall make several simplifying assumptions. First, it will be assumed that the clouds associated with a cyclonic system cover an area at least 400 mi in width and can be represented by a square configuration. Second, we

shall assume that a system can be detected if even a small part of its cloud system comes within viewing range of the satellite. Although this last assumption appears to be somewhat questionable, it becomes more reasonable if we remember that there will be some measure of day-to-day synoptic continuity established.

When the cloud square just touches the edge of the viewing path, the system can no longer be seen. Figure 31 illustrates this (Storm *A*). It will be noted that the width of the viewing path chosen is also 400 mi. We can say, then, that a storm can be seen when the center of its associated cloud system lies within 400 mi of the centerline of any one path. Due to the relatively slow movement of a storm when compared with the progression rate of successive passes of the satellite, the movement of a storm between successive passes ($1\frac{1}{2}$ hr apart) can be neglected.

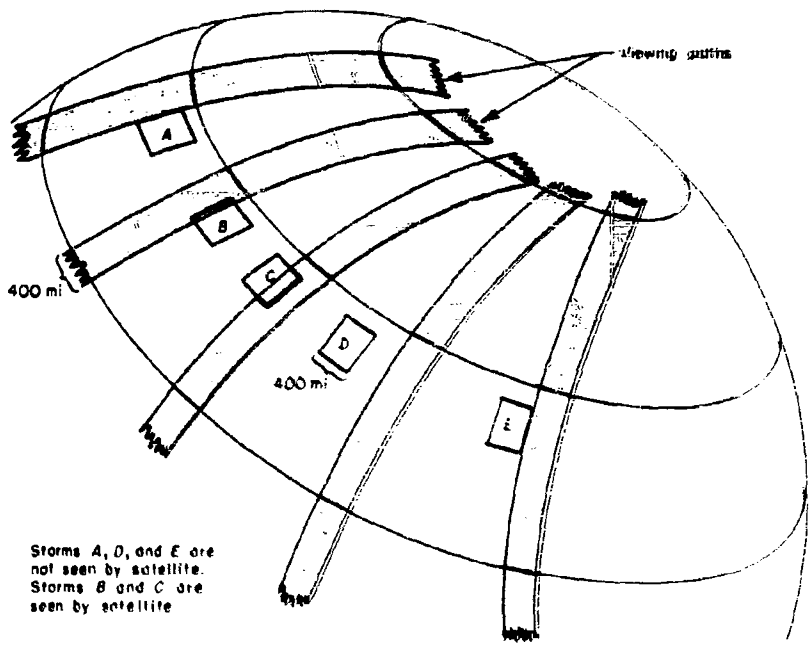


Fig. 31—Schematic illustrating relation between storm location and satellite path

Keeping in mind the fact that the successive passes are evenly spaced in longitude, we can now write down an expression for the probability that a storm will be seen at least once a day:

$$P_\phi = \frac{N(W_p + W_c)}{D_\phi},$$

where N is the number of passes within a distance D_ϕ measured along a given latitude, ϕ is the latitude of the center of the storm system, W_p is the width of the viewing path, and W_c is the width of the cloud square. Using the values of $W_c = 400$ mi, and $W_p = 400$ mi, P_ϕ has been computed and is presented in Fig. 32. As can be seen, the probability of detecting a 400-mi-wide storm any-

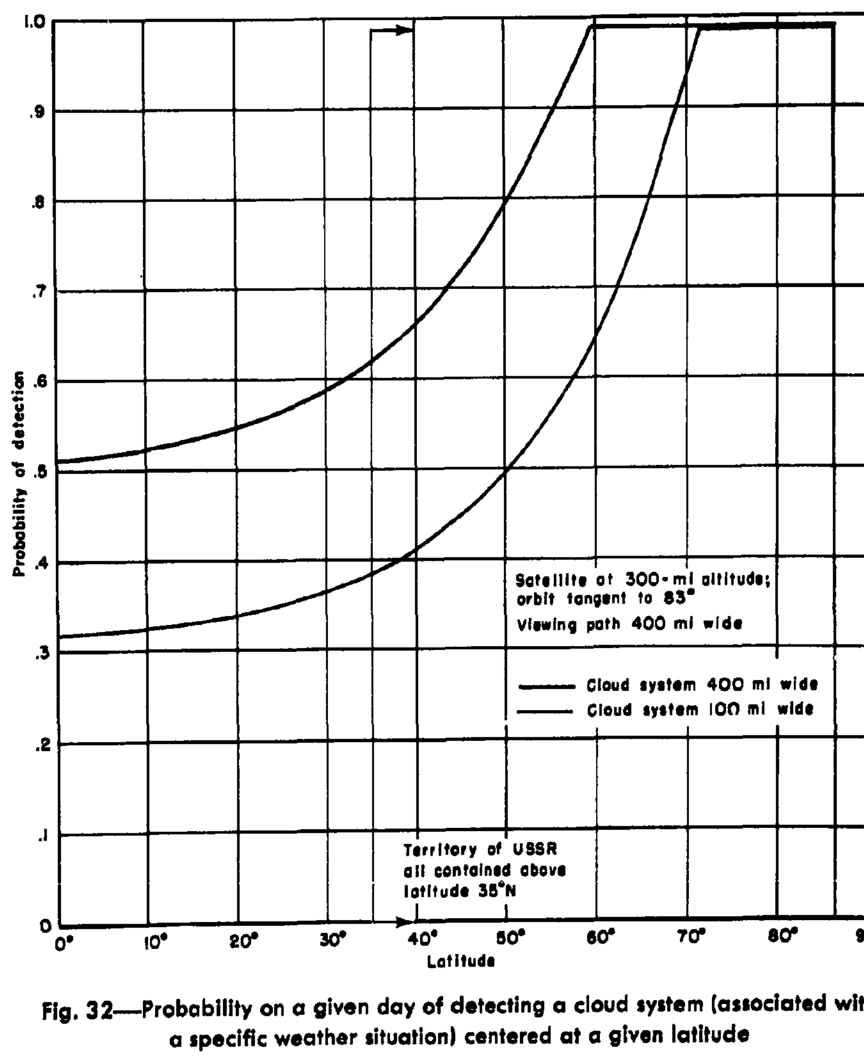


Fig. 32—Probability on a given day of detecting a cloud system (associated with a specific weather situation) centered at a given latitude

where in the USSR is greater than 60 per cent, the probability increasing toward the latitude of tangency (in this case 82°N.). For the sake of comparison, a curve representing a storm width of 100 mi has been plotted on the same figure. In this case, the minimum probability decreases to approximately 40 per cent. However, the average cyclonic storm system is at least 400 mi across, and some are as large as 1000 mi.

Although these probabilities are fairly good, it is understandably more desirable to achieve 100 per cent coverage if possible. It is interesting to note that this can be done with relatively little loss of resolution if the payload television optics are designed especially for weather observations. In the satellite system as visualized, the resolution is bandwidth-limited with the following relationship:

$$f \sim \frac{W_p}{r^2},$$

where r is the minimum resolvable linear ground dimension and f is the bandwidth. Holding the bandwidth constant and tripling the strip width (1200 mi) means that r is increased by only the square root of 3, or 1.732. In other words, the value of r quoted elsewhere in this report as equal to 200 ft is increased to $\sim$ 350 ft. Figure 33 is a plot of the probability of detection with a path width equal to 1200 mi. We see, then, that it is possible to achieve 100 per cent coverage of the area in question with a considerably poorer resolution. It should be pointed out that this minimum resolvable linear surface dimension refers to the area immediately below the satellite, the resolution at the edges of the strip being somewhat worse, due to both increased range and slant viewing. Although this degradation is not marked in the case of the 400-mi-wide strip, it becomes quite considerable for the 1200-mi-wide strip. In the latter case, at the edges the minimum resolvable surface dimension along the path is approximately 610 ft, whereas that transverse to the path is approximately 1750 ft. This resolution is much too coarse for aerial reconnaissance, but it has been shown in a previous report[15] that this is still within the limits of being useful for weather reconnaissance, at least in the parallel direction. In the worst case, this will allow us at least to observe the slope of vertically developed clouds at the edges of the viewing strip, and this in itself can be shown to be a valuable item of information. Of course, the perspective effects could be reduced by using a much greater orbit altitude (say, 1000 mi). However, a completely new vehicle design would be required.

On the basis of this analysis, it appears feasible to do weather reconnaissance from the satellite, at least from the standpoint of area coverage, continuity, and

resolution. It has been shown, moreover, that the demands on a vehicle doing weather reconnaissance are somewhat different from those on one engaged in low-resolution terrestrial reconnaissance. Nevertheless, the latter vehicle can do a substantial part of the weather job without alteration.

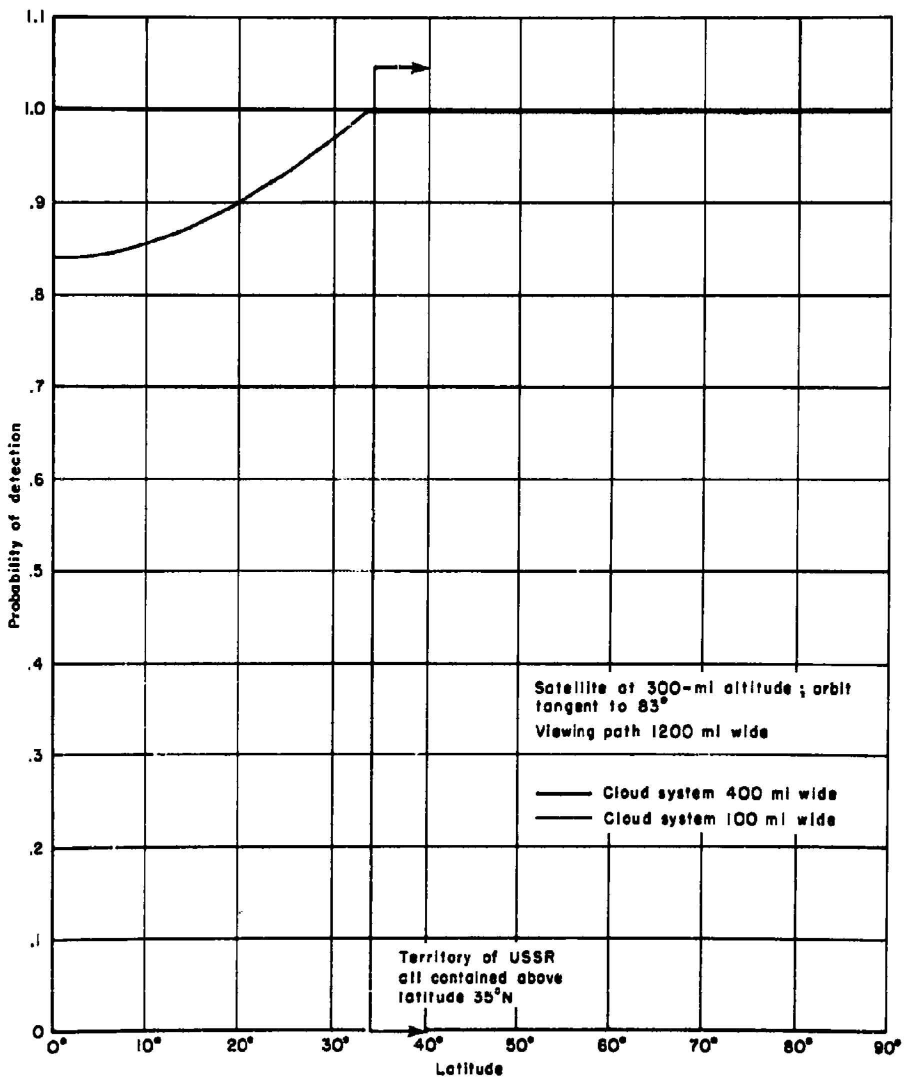


Fig. 33—Probability on a given day of detecting a cloud system centered at a given latitude

VALUE OF FEED BACK RECONNAISSANCE

Lack of basic information concerning the location of SUSAC (Soviet Union Strategic Air Command) bases and other military installations in the USSR constitutes a weakness in our strategic posture that is bound to assume more importance as the USSR makes greater progress in developing nuclear weapons. With considerable thermonuclear and delivery capability, and with their full information regarding U.S. strategic bases, the USSR could deliver a crippling blow against the United States without our being able to retaliate in an effective way. Should the prospect of such an asymmetry continue to limit our strategic planning, we could find ourselves not only in a disadvantageous military position, but also in a progressively weaker political one. The latter aspect is discussed under "Political and Psychological Factors," page 144.

Since conventional strategic intelligence methods are inadequate, this situation calls for novel techniques of prehostilities reconnaissance. Preliminary RAND studies indicate that a satellite device might be expected to supply the needed data concerning the location of Soviet strategic installations. In operation, it would be in effect a strategic equalizer in the field of basic intelligence and would fill one of the most critical gaps in our security, thus shifting the balance of strategic capabilities in favor of the United States.

The value of any reconnaissance effort should properly be measured by its effect on the activity which uses the reconnaissance information, in the sense of increasing over-all capability as well as improving efficiency. In this section, two phases of the Strategic Air Command mission will be considered, and some ways in which the satellite would be useful will be pointed out. First, we examine its use in a campaign against the Soviet strategic air force, which is characterized by a fluid target system and an overriding short-campaign-time requirement. Second, we consider a disruption mission against the Soviet homeland, first against an industrial-plant target system and then against a set of city targets.

The discussion of each of these will include the nature of the particular campaign, intelligence available without a satellite, ways in which the satellite could add both prestrike and poststrike information, and the value of the additional information provided by the satellite measured in terms of its effects on the campaigns.

Soviet Strategic Bombing Capability

Destruction of the Russian strategic bombing capability would be a primary

objective in a major conflict. This objective might be attained by destroying enemy air bases or missile launching sites, or by destroying enemy aircraft or missiles on the ground (ignored here is the slower process of cutting off enemy supplies).

Destroying vehicles on the ground is a sure way to lower enemy strength, but the mission may prove impractical. If manned aircraft have a flyaway capability—and this is largely a matter of warning time—they become a very fluid target. Missiles to be used in a strategic campaign are usually stockpiled in a knocked-down state; therefore component storage could be dispersed or protected passively, so that missiles would not be a lucrative target for attack. Thus it appears that the destruction of the Soviet long-range striking force could best be achieved by attacking their air bases and missile launching sites. Destroying a significant fraction of their air bases would result in a serious disruption of their plans as well as in the loss of aircraft on the ground.

Estimates of enemy capability vary widely. Further, confidence in these estimates is low. The number of air bases which could support a strategic operation against the United States has been estimated at about 160, of which 50 are defined as "home" bases. It has also been suggested that the Russians might use a great many arctic staging bases with packed-snow or aggregate runways. Optimistically, it is anticipated that the United States would know (without the advantage of more intelligence than that currently being obtained) the status of roughly 50 per cent of the primary Soviet air bases well enough to attack them without prior reconnaissance. Viewing the same estimate pessimistically, the Russians might have a large number of air bases of which we would have no knowledge whatever.

Locating the unknown bases by means of post-D-day reconnaissance would delay attacks on these bases and give the enemy added time to use them in an operation against the United States. On the other hand, better intelligence on the enemy's base system could permit immediate denial of most of his bases, with a commensurate decrease in his strategic capability. In this connection, it is important to estimate the value to the United States of destroying various fractions of the enemy's base system. The enemy need not use his entire force or all his bases on each strike. Only after destruction of a substantial fraction of both "home" and "alternative" bases would his capability really be limited.

Since destroyed bases might be rebuilt or repaired (estimates of denial time resulting from atomic attacks are from 2 weeks upward), certain of the bases would have to be reattacked. This means that surveillance would have to be accomplished from time to time after the initial destruction.

Thus an effective campaign against the enemy's air-base system would have several characteristics:

1. It would have to be of short duration, to minimize the time in which the enemy might operate.
2. It would have to include destruction of a high percentage of the bases capable of supporting a strategic operation. This might require a high level of intelligence at the outbreak of hostilities.
3. Surveillance would have to be continuous (or periodic) so that bases which had been repaired might be reattacked.

If information on enemy air bases is to be complete at the outset of the campaign, pre-D-day reconnaissance must be accomplished. Because conditions will change with time, and because the outbreak of hostilities cannot be anticipated with accuracy, the reconnaissance should be continuous.

A satellite could provide the type of information necessary to carry out a campaign against the Russian air-base system. Using a picture scale of 1:500,000 (target cathode in the television camera), the satellite would see conventional airfields, although probably not the arctic bases. At that scale, one vehicle would see all targets in about a month. Under conditions of good contrast, a 1:125,000-scale picture would show aircraft, so that over a period of time the airfields could be identified as to type. At this scale, one vehicle would require a year to see all targets. Even an arctic base could be detected as soon as aircraft were seen using it. Light patterns at night would also help to identify airfields. Photographs of aircraft on the ground might differentiate "home" from "alternative" bases and allow us to attack the most important bases first.

Dummy airfields and/or decoy aircraft would be of dubious value to the Soviet Union if continual surveillance were provided by the satellite. For example, it would be necessary for them to deploy decoys in a fashion similar to live aircraft and to change the number of them on a dummy airfield in order to make the deception effective. On the other hand, the Soviet Union could use such devices successfully to deceive interpretation by conventional means based on isolated photographs.

The pattern and characteristics of Russian airfields and the apparent type of aircraft using them might revise intended Soviet strategy. For instance, the emphasis on TAC versus SAC type of operations might be discerned. Furthermore, traffic patterns might indicate enemy intentions. The build-up of airfield usage could be a signal of possible hostilities. Since the probability of

obtaining complete coverage every 2 weeks would be high, only a few primary bases would escape detection. Certainly the surveillance requirement necessary for selective reattack would be satisfied.

If surface-to-surface missiles were used by the SUSAC for the strategic mission, the detection of launching sites might be required. These sites would not have the runway so characteristic of a manned aircraft installation; but roads, launching pads, assembly facilities, etc., should provide patterns which would be detected by the satellite vehicle. Because earth moving, excavation, etc., would be easily detected, we should almost certainly notice such installations under construction. Here again, because completed missile launching sites might be camouflaged more easily than manned aircraft bases, their detection might well depend on periodic or repeated coverage by the satellite vehicle.

Similar techniques might be employed to detect other vital activities related to the Soviet Union striking force. For example, atomic manufacturing or storage facilities might have some distinctive features that would reveal their locations to the satellite system.

The Disruption Mission

Disruption missions may be accomplished in several ways. An attack can be made against identified individual strategic plants, against industrial-type buildings in general, or against urban areas. We shall consider the ability of the satellite to provide reconnaissance for each of these missions.

At the present time, we know the location of about three-fourths (or less) of the strategic industrial plants in the Soviet Union, largely as a result of intelligence sources available up to 1950. In the future we expect this intelligence to deteriorate because of growth and relocation in Soviet industry, and by 1960 the location of roughly half of the strategic plants will be known. The satellite, however, could provide pictures at scales which would enable us to maintain approximately the present level of knowledge undiminished by the passage of time. In this way, if it seemed desirable to attack strategic industrial plants selectively, the satellite should increase the target-system coverage considerably.

The satellite would provide a capability of locating all strategically important industrial plants. Such an industrial target system would, of course, include many plants whose destruction would not contribute directly to the disruption mission, but these plants would also be destroyed in an attack on a strategic industrial target system. In fact, as larger bombs become available, the coverage

of several industrial plants with a single bomb will become inevitable, and the use of a total industry target system is much better adapted to this type of weapon than a careful selection of small targets would be.

Cities are considered as a target system because industrial plants may be closed by destroying the population with a lower overpressure than is needed to destroy the plants themselves. A city target system will probably require fewer bombs than a total industrial system, since lower overpressures can be used to destroy cities, and this pressure reduction results in larger lethal radii.

Important deficiencies in intelligence information on cities are the target radius and the center of the built-up area, as altered by new growth of the city. Hardness is fairly well known, and population can be estimated from published data on election districts.

A satellite would provide coverage of every city in Soviet-controlled territory for use in attacks on a city target system. Because almost all plants of importance are located near some city, the satellite could provide information for a disruption mission based on attacks on a city target system.

Bomb-damage Assessment

After war started, the satellite would be useful in assessing bomb damage. Poststrike reconnaissance by manned aircraft or missiles would probably receive little emphasis until the first phase of the strategic air war was completed, because of the high cost in combat losses. Indirect bomb-damage assessment (IBDA) would appear to be economical for the bombing systems in which it is technically feasible, but some missile systems might not have this capability.

The satellite capability would depend on the scale and coverage of the television pictures. It would be desirable to determine the actual ground zero (to aid blast-damage evaluation) and the extent of the blast and fire damage. At scales of 1:125,000 there is little doubt that these three quantities could usually be established. The extent of fires would be seen both during and after the burning.

The competence of the satellite would become somewhat less certain at scales of 1:500,000. Probably ground zero could still be located, but the accuracy might be lower. Indications of damage-level circles would be somewhat weaker, but the demolished areas and areas in which the streets were filled with rubble should generally be visible. The extent of fires would also be visible.

Unlike the campaign against SUSAC, the disruption mission would not have to be carried out in a very short time, and the satellite's utility for bomb-

damage assessment would not be particularly reduced by delays caused by bad weather and orbital coverage.

* * *

All the remarks in the preceding discussion of the reconnaissance value of the satellite are applicable whether we use aircraft or missiles to attack the target system. In the case of attack by U.S. missiles, the mapping feature afforded by the satellite assumes increased importance, because a missile cannot exercise judgment, which would be necessary to find a target whose location is only roughly known.

OPERATIONAL SYSTEM STUDY

A logical sequel to a discussion of the nature of the reconnaissance data that can be acquired by means of a television-equipped satellite is a description of the operations and function of a typical system. The example described is only an approximation of the system that may be evolved.

INFORMATION-HANDLING OPERATIONS

In this section an intelligence center for evaluating reconnaissance information, a communications site for receiving data from the vehicle, and finally the space-borne equipment itself will be discussed. Supporting operations, the satellite vehicle, and program requirements will then be considered.

The Intelligence Center

The intelligence center would be the data reduction and storage facility for the Feed Back system. Major functions of this center would be to select pictures of intelligence value from the total input from the communications station, to analyze and report on those pictures, and to store all information for future reference. For maximum effectiveness, the Feed Back intelligence center should be in close contact with other intelligence agencies and should be cognizant of current intelligence requirements. Regardless of input, the center should have a capacity and flexibility consistent with the requirements of using agencies.

Its location should be central and easily reached by air in order to allow rapid delivery of data from the communications station to the user. Security precautions should include duplicate and separate storage facilities for tapes, films, and records.

Operations. The Feed Back system would have a gross output of more than 30 million pictures in one year of operation.* Cloud coverage would reduce

*By comparison, the largest existing depository of aerial photography (USAF Photo Records and Services Division) now has holdings of approximately 30 million pictures accumulated over the past 25 years or more from many sources: military, civilian, and foreign. The present input to this agency is about 20,000 pictures per month.

the useful number to perhaps 15 million, and the screening out of uninteresting areas might further reduce the number to be filed to a few million a year; nevertheless, the handling problem should be fully appreciated.

Feed Back intelligence processing would divide logically into several steps: screening, weather surveillance, target surveillance, brief interpretation, and detailed analysis. There would be some division of intelligence processing between the communications station, where the information would first be received, and the intelligence center, where it would finally be analyzed and stored. Weather and target surveillance of high priority could be done most effectively at the communications station, because the information obtained would be transitory, and the delay involved in transporting tape or film to a central agency would reduce its value. Screening could probably best be done at the intelligence center, because it would involve some specialization and knowledge of previous coverage. All interpretation and analysis, except that required in the surveillance of high-priority targets, would be accomplished at the intelligence center.

Rolls of magnetic tape (or film) would go to the intelligence center. Each roll would contain all the pictures received in one transmission from the vehicle. Recording equipment at the communications station would be linked to tracking and computing equipment so that each roll, and possibly each exposure, could be indexed as it was recorded. The indexing would either be directly in geographic (or other) coordinates or in terms of time, date, and camera orientation so that the translation to appropriate coordinates could be readily made, given the path of the vehicle.*

The first step in data reduction at the intelligence center would be to locate the coverage of a given roll on a map, coded to indicate areas and points of interest and their priority. Valuable sections of that particular roll could thus be determined and projected or reproduced for further study. At first, virtually all areas covered would be of interest and would be subjected to further screening and analysis. As complete coverage was obtained, in a matter of weeks, the initial screening would become increasingly selective and the burden of further analysis would be correspondingly reduced. At intervals, perhaps every 2 or 3 months, the entire area would be re-examined to detect changes or new activity.

The next step in data reduction would be further screening of the pictures. An easy method of performing this second operation would be by projecting (either video or film) individual frames at a suitable scale to show all possible

*Errors in path location could be corrected by using known landmarks as control points.

detail. Rapid scan techniques would be used, probably averaging only a few seconds per frame. Selectors would be highly skilled photographic interpreters with a thorough knowledge of certain areas. All frames which appeared to contain subject matter of interest would be sent on for further analysis.

These frames would then be assigned to special photographic interpreters familiar with the area or target. A brief coded report would be made on each frame, perhaps directly on punch cards. This information would be correlated in an automatic filing system to form a readily accessible body of information on the entire area under surveillance. Using this reference file, detailed analyses could be made of areas and topics of intelligence interest for any period of time desired.

Selectors, interpreters, and analysts would work together, spending as much as half their time in conference and in the study of related data to achieve maximum efficiency in the processing of new data from the system. There would be specialization by topic (airfields, industries, naval activity, etc.) as well as by area and target. The entire process would be regenerative; i.e., accumulated data would allow more inferences to be drawn from new pictures.

There would be several points to consider in discussing the size of the intelligence center. First, the facility would be expected to digest and report information at the same rate at which it was received. The rate would depend on the number of productive vehicles in operation, probably up to a limit permitting complete daily coverage of the total assigned area. Second, the information output of the intelligence center would not need to exceed the ability of the receiving agencies to absorb this information, although some digested data might be simply stored for future reference. It is doubtful that there would ever be more than two or three television reconnaissance vehicles in operation at one time, because this number would give virtually complete coverage daily. It would seem logical, therefore, to design a facility which could handle a continuous load equivalent to the output of one vehicle with one shift of personnel, allowing expansion to three shifts to handle three vehicles.

Equipment. It is assumed that the original transmission would be recorded on magnetic tape. The following list indicates the general types of equipment which would be required at the intelligence center to reproduce, display, select, interpret, catalogue, and file the input from the Feed Back system:

1. *Mosaic printer*—to produce mosaic transparencies from the original data, probably at several scales, and to aid in initial screening and weather analysis.

2. *Plotting board*—to show daily and cumulative coverage as an aid in indexing, screening, and programming.
3. *Selector's display equipment*—to allow rapid display of new coverage and permit automatic indexing and the reproduction of selected frames.
4. *Interpreter's display equipment*—to permit display and retention of selected frames. This equipment could have devices to assist in making counts and measurements, variable contrast and scale, and means of comparison with previous coverage.
5. *Photo reproduction equipment*—to produce negatives or prints as required for reports, etc., operating in conjunction with a video display unit to obtain pictures directly from magnetic tape.
6. *Automatic filing system*—to provide storage for coded reports, tapes, film, mosaics, etc. It should allow rapid access by location, time, subject, and other categories needed for analysis and comparison of coverage.

Ground Communication, Intelligence Center to Communications Sites. Operational communications between the intelligence center and communications stations could be carried out by a long-range radio network or by teletype for stations located in the ZI.* The information which would have to be passed over this net would involve operational decisions, flash reports of preliminary inspection of results, and orbital parameters for use in coordinated reception of traffic at two stations. The quantity of information could easily be handled by part-time use of a single duplex circuit, but there would be times when the precedence requirements would be very high (e.g., continued control and security of the space-to-ground communications might be at stake). Present Airways and Air Communications Service facilities would serve for a part of this traffic and would handle all of it if proper precedence were assigned to it.

A long-range circuit, however, would have insufficient capacity to handle the tremendous volume of intelligence data which could be gathered by a satellite vehicle. Data of a highly perishable nature, such as weather data, could be summarized at the communications station and delivered in map form by facsimile or Wirephoto methods over the long-range net. Detailed television pictures or the magnetic tapes used to store them should be transmitted by air courier—a simple operation, since a day's accumulation of raw data on magnetic tape would weigh about 200 lb.

*Zone of the Interior.

Communications Stations

One or more communications stations would be the ground link between the orbiting vehicle and the intelligence center. The mission of a station would be to receive and record transmissions from the vehicle; to obtain velocity and position information by tracking the vehicle; to predict the acquisition point for subsequent passes; to compute, program, and control the action of equipment on board the vehicle; and to expedite recorded data to the intelligence center.

Capability of year-round operation under isolated conditions probably would be necessary, since a one-station system would require a location in high latitudes, under cold weather conditions. Vital equipment should be designed for short periods of operation of the order of 10 min, separated by planning and maintenance periods of the order of 1 hr.

Factors governing the location of the communications stations are discussed under "Placement of Communications Sites," page 111. Ideally, the stations should be located in U.S. territory at points where useful intelligence could be received as soon as possible after launching. A single station in central or northern Alaska could receive information from all interesting passes of the vehicle with minimum delay.

Provision should be made for processing important or perishable data at the communications station, particularly the surveillance of critical areas and the observation of weather. This indicates a requirement at the communications stations for some means of converting the tape-stored information into photographic information of suitable scale and form. It has been suggested that a display be devised to produce a continuous mosaic from the tape by reversing the vehicle scanning process. Forward station photographic interpreters could then determine the likelihood of conducting detailed interpretation in the areas of urgent military interest, and, if conditions were promising, could blow up individual frames for immediate interpretation.

Functions of the communications station are diagrammed in Fig. 34. Contact with the satellite would be made as soon as possible after the orbit was attained; thereafter, the operating cycle of the station would be as described below.

When the satellite approached the communications range of the station, the vehicle transmitter and receiver would be switched on by the on-board programmer, and the vehicle antennas would be given a preset orientation. The first 20 sec of communication would be allowed for acquisition, after which television transmission of data stored aboard the vehicle would begin, lasting

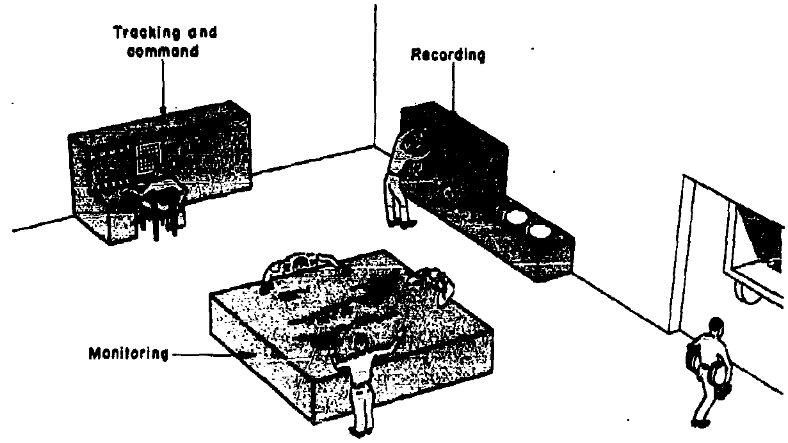


Fig. 34—Functions of communications station

for 5 to 10 min, the television signals being recorded on magnetic tape at the communications station. When the angle of elevation of the vehicle exceeded 5°, tracking-angle data would be accumulated and fed into the orbit computer and predictor. Information from this computer would be routed to the ground programmer for use in controlling the ground and vehicle antennas on the next pass; it would also be routed to the tape recorder for use in indexing the tape with a time or grid reference. Planning information would be fed into the ground programmer and instrumentation. A complete program for the next pass would be transmitted to the vehicle, recorded on board, played back, and checked on the ground within a few seconds.

The communications station should be designed for almost continuous operation with a duty cycle of 10 min every 1.5 hr, since the orbital period would be approximately 1.5 hr in length and there would sometimes be as many as 8 to 10 successive passes with useful information recorded in daylight. In addition, certain night recordings might be of interest. This relatively short time between operating periods would require stand-by spares for equipment which normally could not be repaired in an hour.

Communications Equipment. The principal antennas of the ground equipment would be large parabolic reflectors to receive the transmission from the vehicle and to transmit commands to it (see Fig. 35). With a vehicle antenna diameter of 3.5 ft and a transmitter power of 5 watts, the vehicle transmissions could be received with adequate signal-to-noise ratio for good picture presentation with a ground antenna diameter of 10 ft. This size of antenna could easily

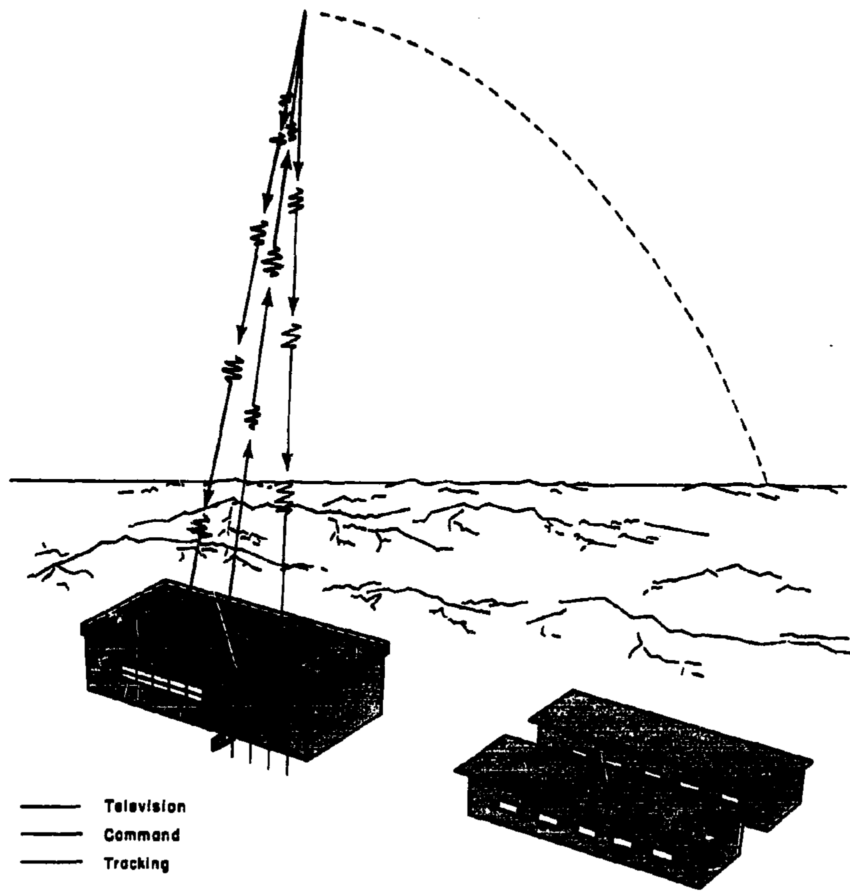


Fig. 35—Antenna installation for tracking and for command radar and television reception

be managed, and a small factor of safety could be added to the system by the use of a 20-ft-diameter ground antenna. Because an accuracy of pointing of about ¼ deg would be required, and the fastest motion would be 1 deg/sec, the fabrication of a mount for the 20-ft antenna would present no special problems. Use of the same mount for both receiving and transmitting antennas would guarantee that both dishes would remain accurately aligned. Choice of antenna size should be based on engineering studies dealing with the actual transmitter power tubes and other components available at the time of construction.

The receivers in the ground equipment would have several channels with bandwidths and detector characteristics matched to the type of data for which they were intended. One channel to be used for tracking would be quite narrow in band, so that it would have the best signal-to-noise ratio for a slow tracking operation. During the times that accurate tracking information would be collected, the antenna beam could be modulated a small amount by conical scanning. The resulting amplitude modulation on the received signal could then be compared in phase with the scanning motion in the track error detector and used to develop two error signals for the orbit computer. Receivers for the data channels would feed the television data to storage and display units as required.

The control of the motion of the large antenna would be carried out by an electromechanical antenna control unit which would be directed by the output of the orbit computer and predictor. This computer would be primarily a storage device containing the predicted orbit as a function of time, a predictor which would correct orbit data in the light of new tracking information, and a parallax computer which would compute the directions from the ground station to the vehicle as a function of time. If several vehicles were in use in slightly different orbits, the same computing machinery could serve all of them, provided that a separate storage were built for the orbit of each vehicle. Actual computing operations could be carried out on a digital basis, and the storage could be made in the form of numbers printed on magnetic tapes.

It is believed that one standard computer such as an IBM 701 would probably more than suffice for this purpose, although it is likely that a specialized piece of equipment would be designed to do the job.

The prediction of future positions of the vehicle at specified times would be carried from the orbit computer to the programmer, where operating decisions would be made concerning the mode and scale of intelligence-data collection, the times of collection, storage, and transmission, the collection of calibration data over the United States, and other factors concerned with the operation. These decisions would be incorporated with predicted position data to make up operating programs for the vehicle. Operating programs would be taped in advance of contact with the vehicle, and the tapes would be checked for errors by the programmer. A time interval for command transmission would be programmed, and the taped program would be transferred to the vehicle through the command transmitter during the contact. Aboard the vehicle, the command data would be stored on a memory drum and would also be repeated back to the ground station to be checked against the initial decisions. The ground com-

mand transmitter would operate in the X-band and would have a frequency displaced differing from that of the vehicle transmitter.

The design of the ground communication equipment should emphasize reliability and ease of maintenance at the expense of size, weight, and power consumption. Any portion of the equipment subject to frequent failures should be duplicated so that a stand-by capacity to replace the defective component could be maintained. In view of the high carrier frequency required, it would probably prove desirable to mount the radio-frequency parts of the receivers and the command transmitter on the antenna mechanism so that no long leads or rotary joints would be required to operate at radio frequencies. Other data-processing, computing, control, storage, and display equipment could be built in readily accessible rack and panel construction with convenient operating desks for programming and data inspection.

Vehicle-borne Facility

The handling of the television signal received from the vehicle has been discussed above. It is now appropriate to show (1) the type of television chain that might be employed, and (2) the physical and engineering constraints to which it would have to adhere.

Description. Both RAND and the Radio Corporation of America[14,18-26] (under subcontract to RAND) have examined various possible visual information pickup systems for the satellite. A schematic of the most promising system is shown in Fig. 36. As foreseen at the present time, the actual pickup device would be a standard studio-type 3-in. Image Orthicon television camera surrounded by somewhat better than standard (but presently available) circuitry. Greater detail on the system selected, plus discussion of other systems, may be found in Vol. II.

Briefly, the ground scenes would be projected by an optical system into two cameras (operating in sequence). Included in the optics would be a scanning drum having a number of mirror pairs, each of which would present a given segment of the ground. Signals would then pass from the cameras into the tape storage and subsequently would be played back through the transmitter and vehicle antenna for ground reception when the vehicle came into ground communication range.

In reality, two systems have been expounded, differing in optical scale factor: a "mapping" system at 1:500,000 and a "reconnaissance" system at 1:125,000. Under "Photographic Reconnaissance Intelligence," page 17, a discussion was

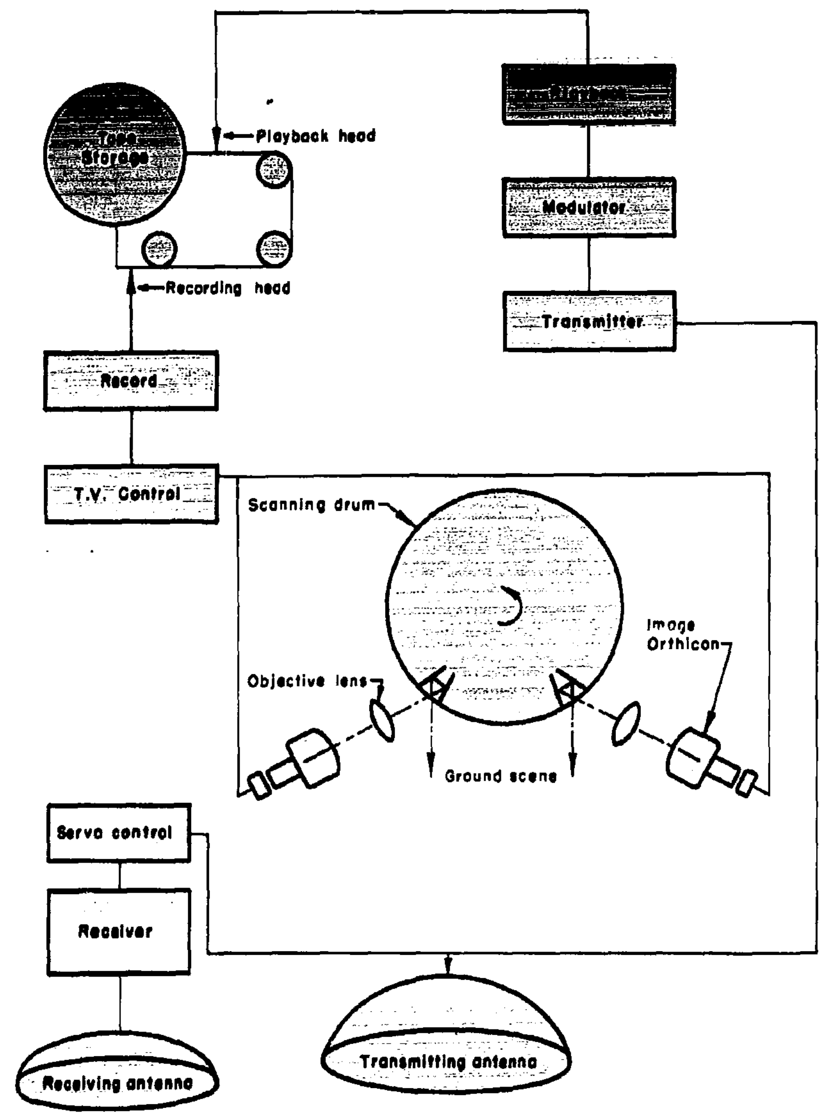


Fig. 36—Schematic of television system

given of photographic interpretation at those two scales. It was seen there that the scale factor of 1:500,000 would yield certain exploratory or pioneer types of reconnaissance and weather data as well as mapping information. This is considered as a more or less standard system, probably to be embodied in the initial satellite vehicles.

A larger-scale system (perhaps 1:125,000) would probably be used in subsequent vehicles to provide more detailed information on ground targets and possibly to conduct a surveillance type of operation. In our discussion the large-scale system will be considered as being a modification of the first or standard system.

The standard system (1:500,000 scale factor) should be able to resolve isolated objects of 70-ft size where these objects are presented with high contrast against a uniform background. In general, with average contrasts (including haze effects), a minimum resolvable surface dimension closer to 200 ft would be expected.

Pertinent features of the standard system would be:

Scanned area per frame	7.6 × 10.1 stat mi
Width of strip on ground that is scanned	374 stat mi
Picture frame rate	23/sec
Active TV lines/frame	558
Bandwidth	6.5 Mc
Optical focal length	38 in.
Optical system speed	f/17

Side-to-side scan would be provided by a 3-ft-diameter drum containing 18 mirror pairs to immobilize side-to-side motion (200 mi of ground/sec) for a given frame and yet furnish a continuous motion for the drum. The two Image Orthicon camera tubes operating alternately would provide 36 frames per scanned strip.

Forward immobilization (to compensate for the vehicle speed over the ground of 4⅝ mi/sec) would be accomplished by allowing the optical image to remain on the camera target only 1½ ms and, further, by electronic compensation of motion of charge pattern on this target.

Something on the order of a month would be needed to obtain pictures of all ground targets, provided that average weather was encountered. It will be noted that at a larger scale a correspondingly longer period would be needed to acquire comprehensive coverage of ground targets.

The larger-scale, or "reconnaissance," system would be similar to the above system, but would of course have different values for various parameters.

An f/25, 152-in.-focal-length optical path feeding into a 23-in. drum with 5 mirror pairs would be indicated. The scanned width on the ground would then be 23 mi. As discussed previously, a longer time (nearly a year) would be needed to cover all ground targets with this latter system, allowing for cloud-cover effects.

With either system, about 8 Mc/sec bandwidth capability would be desirable for the circuitry accompanying the television tubes. Owing to the need for recording and playback of the television information (to eliminate forward tracking stations), a magnetic-tape storage system is considered an essential part of the television system. A video magnetic-tape recorder of the order of 1.5-Mc bandwidth has been demonstrated both by Radio Corporation of America and by Bing Crosby Enterprises. The extension of this to 8 Mc, coupled with the simultaneous shrinking of the equipment to a reasonable size and weight (200 lb), is felt to be possible from an engineering standpoint. Further research should be conducted to establish this point.

A modulator and X-band (7500 Mc) transmitter, with proper antenna and tracking devices, are believed to be straightforward developments, with the exception perhaps of the transmitter output tube. Here reasonable efficiency combined with a 1-year lifetime is of some concern.

Presently available tubes include the magnetron, having suitable efficiency but inadequate life, and the klystron, having a life expectancy of 1 year but high power consumption. It was found that the use of klystrons (2) instead of a magnetron would increase the over-all system power consumption by 25 per cent. Since the power required by the payload is already in the regime where a nuclear reactor is needed, this additional power and attendant weight increase (skin radiator) is probably justified in view of the reliability of the klystron. However, future studies should follow the improvement of the magnetron and consider the use of the traveling-wave tube.

Television System Constraints. A major factor in the television performance is picture resolution, or resolving power. To define the optical characteristics of a given system by a single number such as the "resolution index" is perhaps inadequate. Optical resolution is defined as the ability to distinguish a pattern of lines as separate forms. The so-called optical line is the distance measured from one of the lines in the pattern to the next adjacent line. The television line index is comparable, except that two television lines equal one optical line.

The 558 (active) television lines (or 279 optical lines) across the photocathode determine the resolution of the tube for the standard television system assumed for the Feed Back vehicle.

It is usually necessary to have several television lines encompass an object viewed by the television system in order clearly to identify it in a pattern, particularly when ordinary contrast ratios are encountered. By "ordinary control" we mean the relation of a dark gray object to a light gray object, rather than a black object against a white background. Thus, as was noted previously, a minimum resolvable surface dimension of 70 ft can be computed for the so-called standard system, whereas, in reality, something of the order of a 200-ft dimension would be all that could be resolved in practice.

In view of the inadequacy of the single index for resolution, a much more appropriate way to describe resolution capabilities is to present the visual response as a function of signal frequency. Various types of viewing systems (photographic film, the human eye, and television [or other] pickup tubes) have different responses in different regions of frequency. A single-resolution index, however, only tells of the cutoff point or highest frequency of information that can be clearly distinguished by the system. Figure 37 shows a comparison between a television response curve and a photographic-film response defined as a signal amplitude. Although photographic film can detect information at higher frequencies (finer resolution) than can a television camera, in the high-frequency end of the spectrum the film has a long tail of relatively low response. If the television curve is considered, it will be seen that its response exceeds that of photographic film for a considerable region of the lower frequencies up almost to the frequency corresponding to the resolution

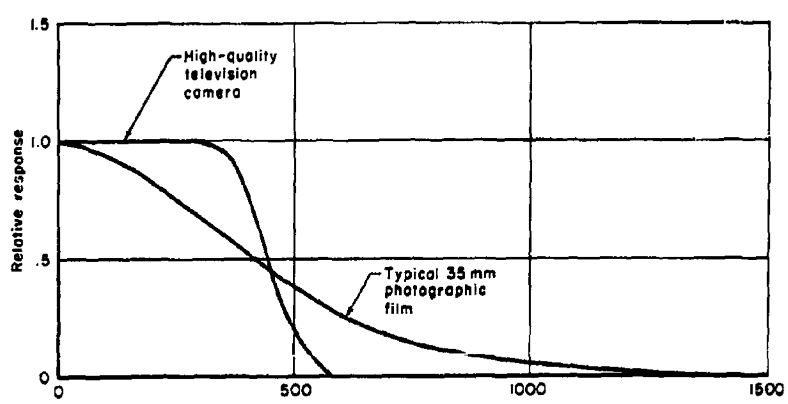


Fig. 37—Comparison of photographic-film and television-camera response characteristics at various television line numbers (signal bandwidth)

index of the television system. At this point the television signal amplitude falls off to zero quite rapidly.

Tentative conclusions may be drawn from these typical curves. Although photographic film may show a severalfold improvement over television on the basis of a single resolution index, the total information content of the television signal is not far below that of the photographic film. With only a slight amount of degradation in the system, the high-resolution advantage of the photographic film can be destroyed, whereas the strong response of the television system at medium frequencies (i.e., medium resolution levels) is considered to be valuable from the standpoint of photographic interpretation.

Detail in a recorded ground scene is valuable to the extent that the photographic interpreter can assimilate and evaluate it, much of the end result being tied up with the physiology and psychology of the eye-brain combination. Medium-sized objects can be detected by the eye at lower contrast values than can very small objects.[27] The eye, therefore, tends to reduce the value of the outer, high-frequency end of the "film" curve of Fig. 37. For any given useful print size (based on the number of scenes that can be handled in a day by each photographic interpreter), a television picture will be about equal to a photograph taken at the same focal length, but will be a trifle better than the photograph for objects slightly larger than the television resolution limit.

An overriding criterion for the system would be the rate at which information could be acquired and transmitted back from the vehicle. The satellite's rate of information would be comparable to a bandwidth (at 7500-Mc frequency) of several megacycles per second. All components of the system should be compatible with the design bandwidth; e.g., in an 8-Mc bandwidth system, it would be logical to use a pickup system that has an equivalent total bandwidth.

For a given bandwidth, the fineness of detail that is to be observed on the ground depends on the focal length of the optical system employed. Conversely, for a given focal length and a given system bandwidth, a unique rate of ground-area coverage exists. Thus, if it is necessary to view smaller objects on the ground, this can be done for a given bandwidth by increasing the optical focal length and accepting a decrease in the total amount of area covered in a given length of time. Compromise can be made as to whether the ground area is to be covered by unconnected "spot" views or as a continuous strip.

In Vol. II, the advantage of using the Image-Orthicon type of television-camera tube over other pickup devices will be discussed. Although the photo-

conductive type of television tube, of which the Vidicon is one example, should be theoretically more light-sensitive than the photoemissive type (Image Orthicon), practically speaking the full potential of the Vidicon has not been realized to date. Indeed, the resultant sensitivity of the Vidicon, due to slow "erasure" properties, is quite a bit poorer than that of the Image Orthicon. The main use of the Vidicon is in applications where light level can be set quite high—for instance, in film copying. Thus, although the Vidicon has advantages over the Image Orthicon in simplicity, power requirement, and size, and although it has the same inherent resolution as the Image Orthicon, the latter must be considered preferable at the present time. Later on, Vidicon developments may alter the choice.

In this study, a standard studio 3-in. Orthicon camera tube has been assumed, producing a resolution of something less than 600 television lines. Laboratory Image Orthicons have been built to resolutions of the order of 1500 television lines, using a larger target size in a 4½-in. tube. This latter television tube was first built by O. H. Schade, of RCA, and some of the first pictures were taken about 7 years ago. In present-day usage there is apparently no great commercial demand for high resolution in standard studio broadcast television tubes, since in the last few years the resolution characteristics of the standard Image Orthicon have not been materially improved (owing partially, of course, to the Federal Communications Commission bandwidth regulation of the standard studio broadcast to the order of 3½ Mc). Figure 38 is a photograph taken by Schade of a presentation by the 4½-in. Image Orthicon using a 20-Mc bandwidth.

Thus, the over-all requirements of the system must be examined carefully; it is not at all obvious that the tube resolution would completely typify the system. The payload that has been assumed here would use the standard 3-in. Image Orthicon. Part of this choice was based on the inherent reliability that would probably result from selecting several high-quality specimens out of a large production of standard tubes. The choice was also related to the design of the over-all system. If we were to use, say, the 4½-in. Image Orthicon, the optical scan drum would have to be larger in proportion to the increased tube resolution, with corresponding increases in weight. Furthermore, power requirements, the size of the transmitter, the size of the antenna dish—all would be increased.

Assuming that the 3-in. Image Orthicon were used as the pickup camera component (actually there would be two such camera tubes in the vehicle),

quite a few of the characteristics of this system would be certain, in view of present-day experience. Volume II lists the various characteristics.

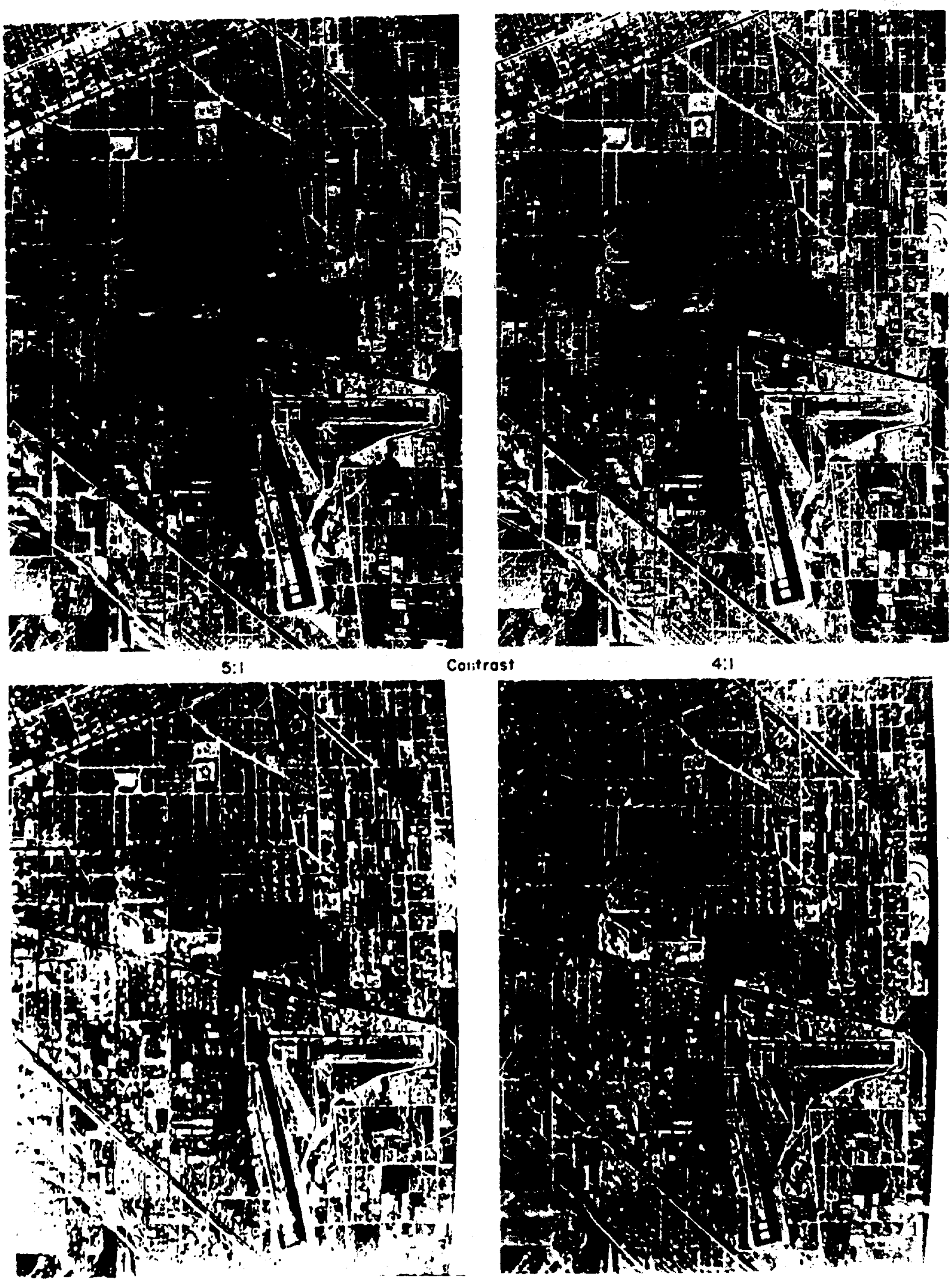
Preceding paragraphs have been concerned with the quality of the televising equipment and its ability to resolve detail for average contrast. Contrast of ground scenes will vary considerably, due to haze, character of scene, time of day, and season of the year. Although the television tube seemed to be able to cope with low-contrast scenes (particularly when due to haze), at least as well as would camera film, some tests were made to verify this capability.

The experiment consisted in taking an original print of an aerial photograph with maximum contrast of about 5:1 and reproducing this original print at contrasts ranging from 2:1 to 5:1 (by varying print exposures in the darkroom). The original print and reproductions were then imaged and recorded by a television camera using a high-quality television chain; bias in the television camera was adjusted to compensate for the contrast change. There was a noticeable but much less than proportional increase in performance, i.e., ability to recognize detail, in going from the television reproductions of the pictures of 2:1 contrast to those of 5:1. However, at an original scene contrast of 2:1 it was still possible to detect aircraft of about 100-ft wing span and body length at a photocathode scale of about 1:140,000. Figure 39 contains prints of resulting pictures.

To get the resolution required, the effects of vibration in the vehicle would have to be very small: a problem which could be investigated completely beforehand and handled by adequate balancing and mounting, at least. Other considerations would be those of the special designing of any pieces of equipment which might tend to cause vibration (rotating parts would be preferred to reciprocating parts, and so on). The change of focal setting of equipment due to temperature changes would not be so predictable. Therefore it would probably be necessary to have fairly close temperature limits on the optical system as well as on the Image Orthicon. Additional considerations of the optical system may be found in Vol. II.

Fig. 38—Television picture of Los Angeles Harbor taken by Otto Schade, of RCA (width of area shown: 4¼ mi)

Original photographs



Television pictures

Fig. 39a—Effect of scene contrast on television picture quality

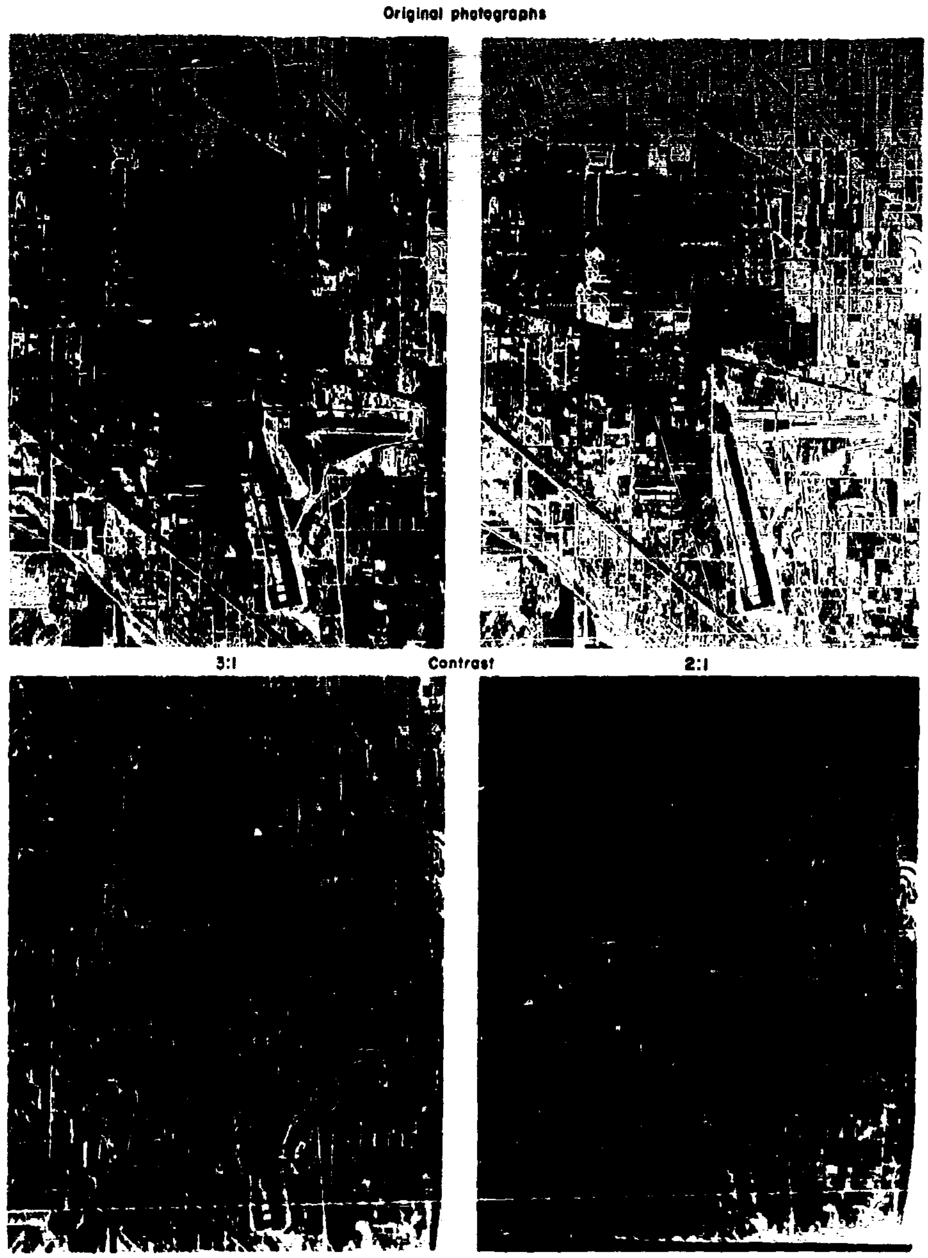


Fig. 39b—Effect of scene contrast on television-picture quality

SUPPORTING OPERATIONS

As integral parts of the Feed Back system, the choice of orbit, the placement of communication sites, the command link, and launching merit some discussion.

Choice of Orbit

Orbital Properties of the Satellite. If the satellite has the correct velocity, the centrifugal force developed will balance the earth's gravity pull, resulting in a circular orbit about the earth.

If the motion is slightly off the horizontal, or if the centrifugal force of the satellite's motion is slightly larger or smaller than the earth's gravitational force, the satellite will move in a slightly eccentric ellipse with the earth at one focus. However, the guidance system assumed in this report would establish a nearly circular orbit, and the ensuing discussion considers such a case. Figure 40 shows the speed and period of an earth satellite as a function of altitudes between 200 and 600 stat mi. Near the earth, a speed of about 25,000 ft/sec is indicated, whereas at higher altitudes this figure is lower.

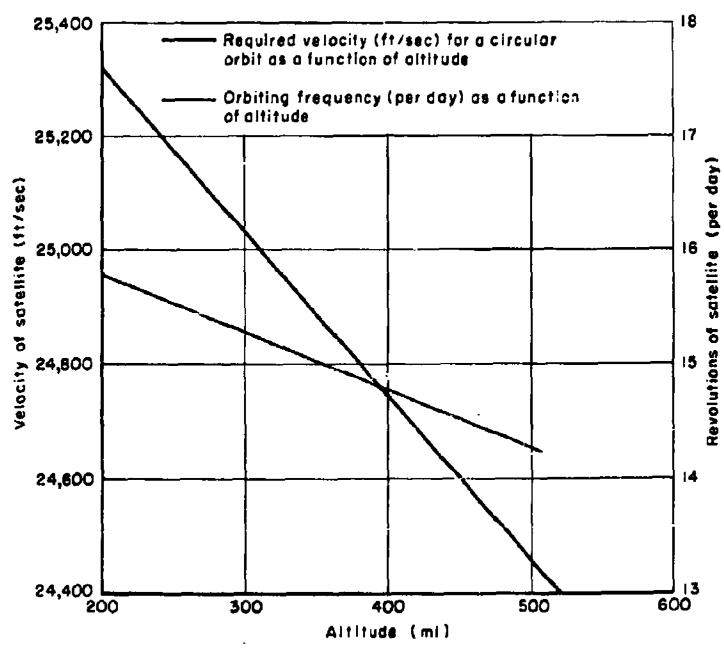


Fig. 40—Satellite velocity and orbiting frequency vs altitude

The unperturbed orbit plane changes very slowly with respect to inertial space. Even with perturbation (to be discussed below) the plane rotates about 1° of longitude per day. Thus, the earth revolves relative to the orbit plane about once a day. In this same interval the satellite would revolve approximately 16 times around the earth.

The angle between the orbit plane and the equatorial plane (here defined as the inclination angle) would be a function of the initial conditions of motion of the vehicle when established on orbit and therefore would be arbitrary. Since the orbit plane contains the earth's center, it is obvious that the vehicle could not go beyond the zone of latitudes corresponding numerically to the inclination angle. For example, if complete surveillance of Russia was desired, an orbit of 78° inclination encompassing the latitude zone ± 78° would be necessary.

Figure 41 illustrates the effects of combined earth and satellite motions (as found in any doubly periodic system) and the geography lying below successive passes for a vehicle at an altitude of 300 mi. For each succeeding revolution of the satellite, the earth's surface beneath the vehicle would be displaced eastward about 23° in longitude. In Fig. 41 the lower circle is the earth viewed at an angle such that both the equatorial plane and the plane of the satellite's motion are seen on edge to illustrate the meaning of the inclination angle. The

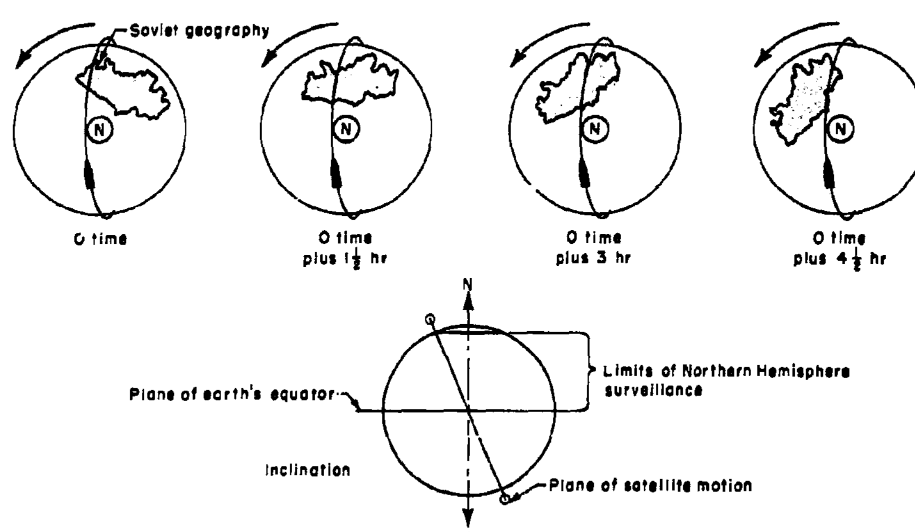


Fig. 41—Principal effect of combined earth-satellite motion

upper figures represent the earth as viewed from above the North Pole, showing the relative motion of the earth's surface for successive passes of the vehicle around the earth.

In the preceding paragraphs, a number of effects have been ignored which disturb the orbit from the space-fixed (nearly circular) ellipse described. Among these are the gravitational attraction of the sun, moon, and planets, and the equatorial bulge of the earth. Spitzer (in Ref. 13) has shown that the effects of the sun and moon (and by inference, the planets) are insignificant. The effects of the oblateness of the earth, which have been treated by Brouwer,[28] MacMillan,[29] and Roberson[30] are significant and must be considered in connection with the data-collection operation.

Two effects result from the earth's oblateness. First, the whole orbital plane revolves slowly about the earth's polar axis. The angular velocity of this revolution depends on the inclination of the orbit to the equator, becoming zero for an orbit which passes over the poles. This effect is called the "regression of the nodes," and is similar to the familiar precession of a gyroscope. Second, the major and minor axes of the elliptical orbit undergo a slow angular motion in the plane of the orbit as a secondary effect, called the "precession of the perigee" (unimportant here because the orbit is nearly circular).

In summary, the orbit about a spherical earth can be regarded as a rigid, nearly circular ellipse. When the effect of the bulge in the earth is inserted, the ellipse is practically unchanged but begins to move as a rigid body with a slow angular velocity. The significant component of angular velocity is the regression of nodes, and this regression is operationally important.

If the general motion of the satellite in its orbit is from east to west, the orbit plane regresses to the east. Westward motion of the vehicle in the orbit may be defined as "retrograde," since it will be in an opposite sense to the earth's rotation. Figure 42 shows the appearance of a retrograde orbit as viewed by an observer fixed in inertial space above the north pole of the earth. The regression rate and the period for a complete revolution of the earth about the polar axis as functions of inclination for several mean orbital altitudes are given in Fig. 43.

Selection of Orbit Parameters. It is pertinent now to outline the procedure leading to the choice of the appropriate orbital altitude and inclination.

These factors improve with *increasing* altitude:

1. The duration in orbit, because of reduced atmospheric drag.
2. The increase of line-of-sight horizon distance for communication.

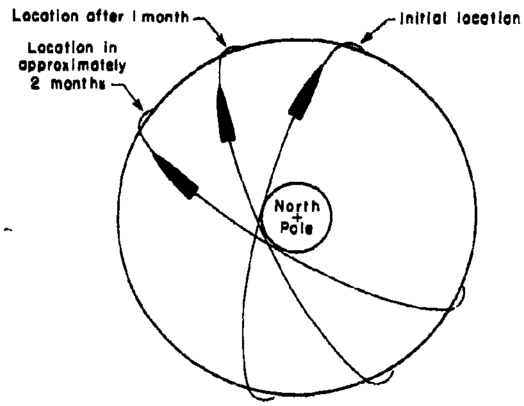


Fig. 42—Regression as viewed looking down on earth's North Pole

3. The reduction in obliquity in pictures taken at a given distance to the side of the satellite path.
4. The differential image immobilization effects, due to a given differential error in orbital altitude.

These factors improve with *decreasing* altitude:

1. The size of the optical system needed to obtain a given resolution or scale of picture on the television photocathode.
2. The amount of energy required to establish the vehicle in its orbit.

It is felt to be desirable to have the satellite at an altitude such that atmospheric drag will not pull it to earth before at least a year. An analysis based on reasonably conservative estimates of the density of the upper atmosphere indicates an orbital duration of about 3 years for a 300-mi altitude.

With respect to line-of-sight communication with the ground, the higher the satellite the farther it will be able to see. For a satellite television system using tape-recorded playback, 300 mi of altitude would give adequate line-of-sight distance for communication with the ground. The effects of the other factors listed above are minor, by comparison. For example, the difference in vehicle gross weight would be only about 2 or 3 per cent for a 50-mi altitude change. However, it would be necessary, because of line-of-sight requirements, to increase the satellite's altitude to 500 mi if a television satellite system without the tape-recording feature were to be employed. Because recording is assumed, a 300-mi altitude would seem to be a logical choice.

The next parameter to be considered is the inclination angle. It will be re-

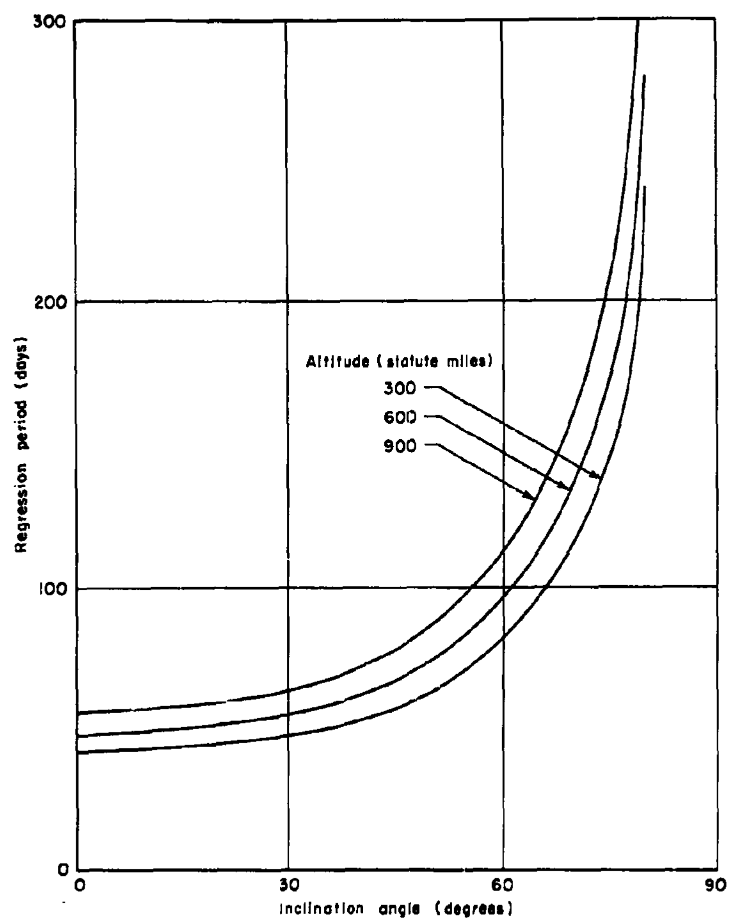


Fig. 43—Regression period as a function of inclination angle

called that Soviet geography extends to the 78th parallel. An 83° retrograde orbit may be chosen because of a unique rate in relation to the earth's seasons. This feature can be shown by several illustrations involving relative motions of the earth, the satellite, and the sun throughout the year. Figure 44 shows the earth and a polar satellite (90° inclination angle) in various positions throughout the year. The viewpoint is a quasi-inertial one looking down on the earth-sun system from the direction of the North Star. The earth's spin axis (which is inclined at about 23½° to the plane of the earth's orbit around the sun) is then seen as a point, and the apparent circular shape of the earth's orbit is somewhat misrepresented.

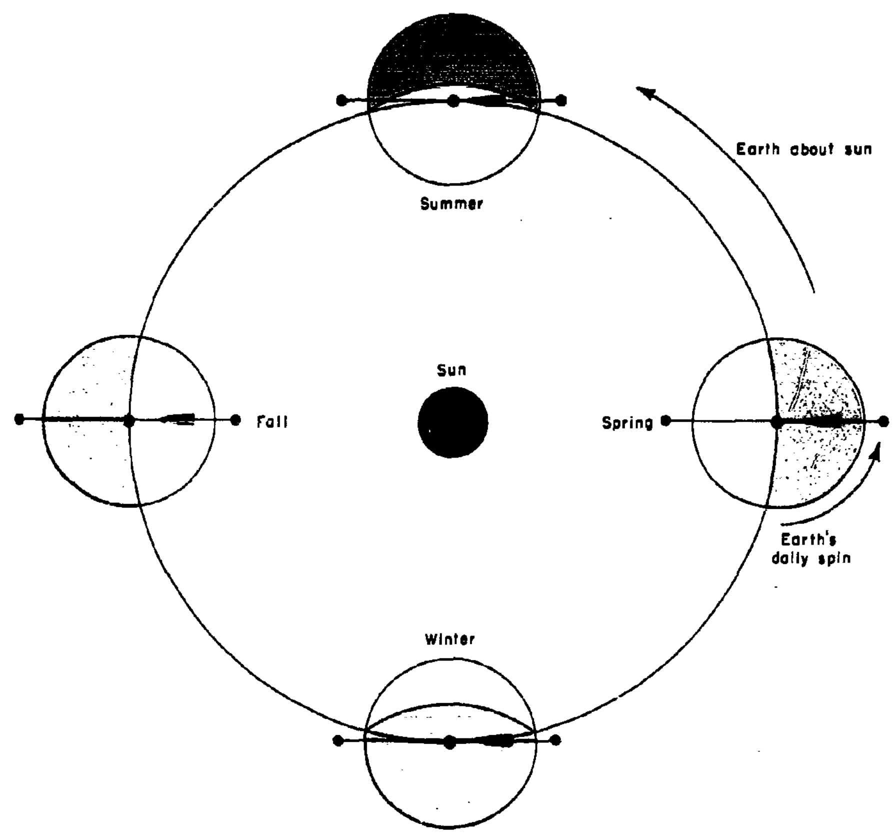


Fig. 44—Schematic of effect of seasons on satellite orbit which is nonrotating with respect to inertial space

Figure 43 shows that a satellite following a polar orbit would not regress with respect to inertial space. In the view of Fig. 44, looking down on the earth's spin axis, the plane of the satellite's motion is seen on edge (and hence as a line), and the direction of this line does not change throughout the year. If a polar satellite were launched in the spring, so that interesting points in the Northern Hemisphere would be observed at approximately noon, in summer these points would be seen only when the sun was close to the horizon. If the orbit is inclined at 83° and is retrograde(passing to the left of the North Pole), it regresses at about 1° per day and in 1 year will regress through about 360°. Figure 45 shows the advantage of this yearly regression period on the daylight coverage throughout the year. It is noted that, because of the yearly regression

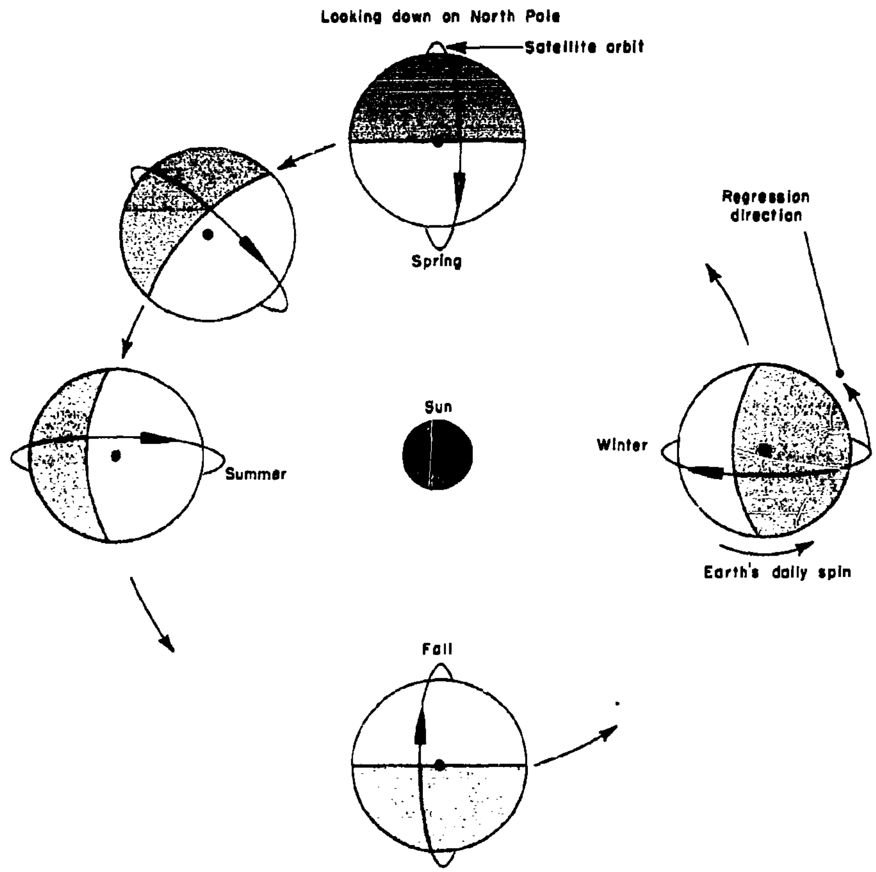


Fig. 45—Effect of seasons on satellite (83° retrograde orbit)

period of the 83° retrograde orbit, the satellite would be able to operate in maximum daylight brightness over targets of interest throughout all seasons of the year.

With an 83° orbit, a change of 1° in inclination would result in a variation in the regression period of about 50 days. It will be shown under "Guidance and Control," page 127, that the tolerance for establishing the orbit (based on anticipated initial guidance accuracy) would be about 0.1° in azimuth. This would introduce a 5-day or 1½ per cent uncertainty in the yearly regression period.

Ground Coverage Attained by Successive Revolutions of the Satellite. Reasons have been shown for choosing a retrograde orbit of 83° inclination and an altitude of 300 mi.

Consideration can now be given to the satellite's capability, following this chosen orbit, of obtaining picture coverage of a given large surface area such as Russia. Figure 42 showed that rotation of the earth about its own spin axis would bring into view parts of the earth's surface displaced about 23° of longitude for every consecutive revolution of the satellite. The exact magnitude of this displacement would be determined by the length of a day, the satellite's period, and the regression rate of the satellite's plane of motion.

It will be recalled from an earlier section, "Vehicle-borne Facility," page 93, that the satellite would observe terrain by means of an optical scanning system which would allow it to look a certain distance on either side of its path. The possibility of rather rapid coverage of the entire Soviet Union would be provided for if the scan was wide enough. Figure 46 shows how these longitudinal displacement considerations, combined with a 400-mi scanned width, would provide the possibility of complete coverage in only a few days. At the northern regions, complete coverage would be possible each day. Farther south it would take several days.

The description above outlines the geometrical-geographical considerations which would provide the opportunity of seeing an object on the ground. However, it would also be necessary that the weather be taken into account. Considering weather alone, the probability of observing a given point on the ground as a function of the number of independent observations is shown in Fig. 47.

Combining the above probabilities allows computation of the percentage of ground area seen as a function of specified latitude and the number of days of operation (Fig. 48). It is assumed that the television scanning-strip width is 400 mi.

Notice that complete coverage develops more rapidly at high latitudes, but is nearly 100 per cent in all cases after several weeks' time.

Placement of Communications Sites

In this section, consideration is given to the factors leading to satisfactory location, description, and operation of the ground-based sites for communication with the vehicle.

Locations of communications sites must be chosen carefully. Political and physical safety factors will affect the choice of appropriate station locations. Those located on foreign friendly soil or near the USSR (e.g., on the high seas)

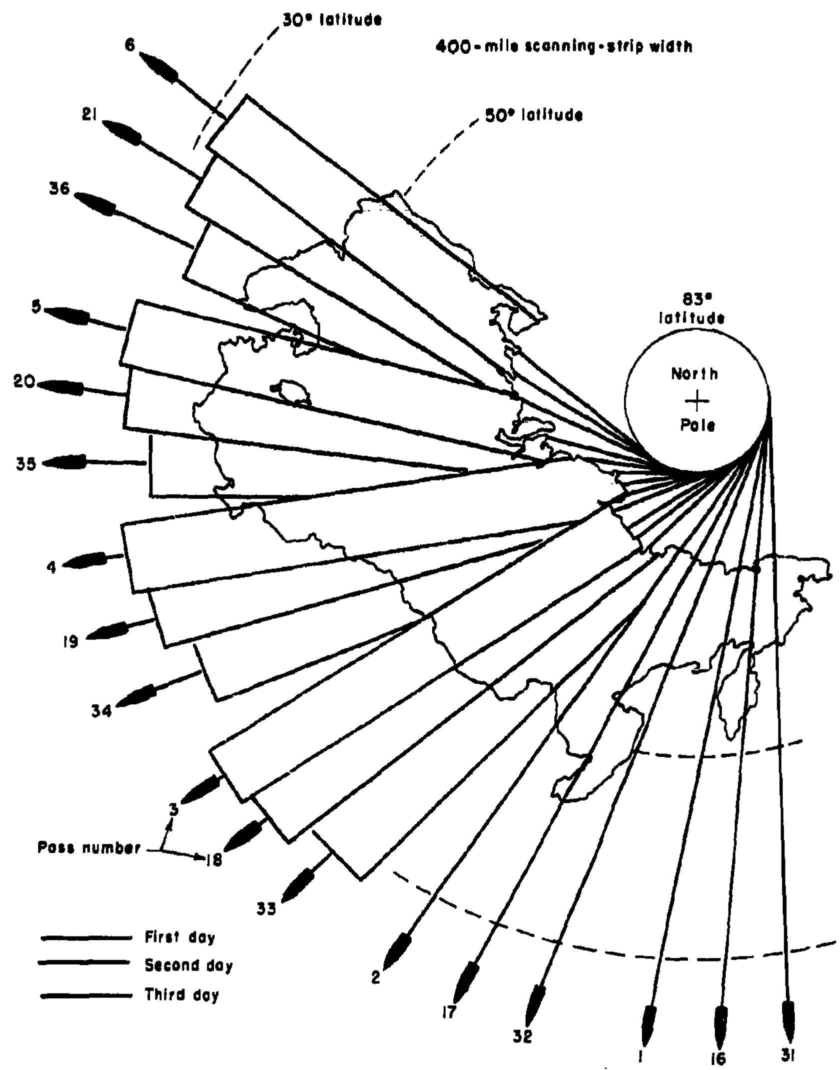


Fig. 46—Coverage of Russia with 3-days' operation of satellite

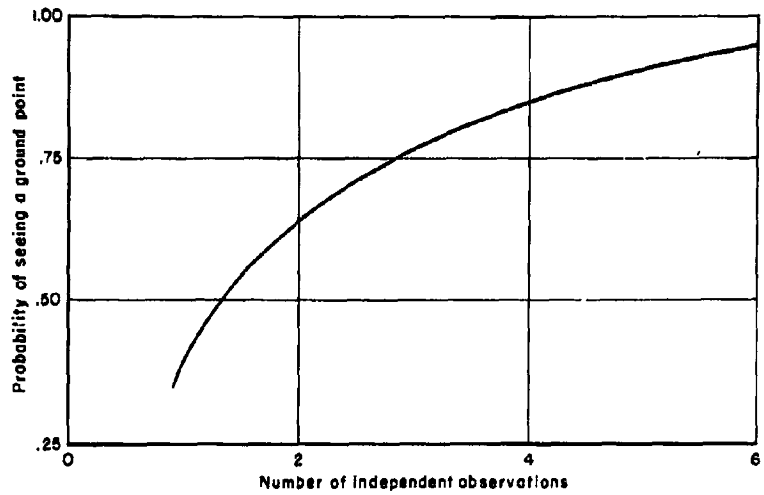


Fig. 47—Probability of seeing a point as a function of number of observations

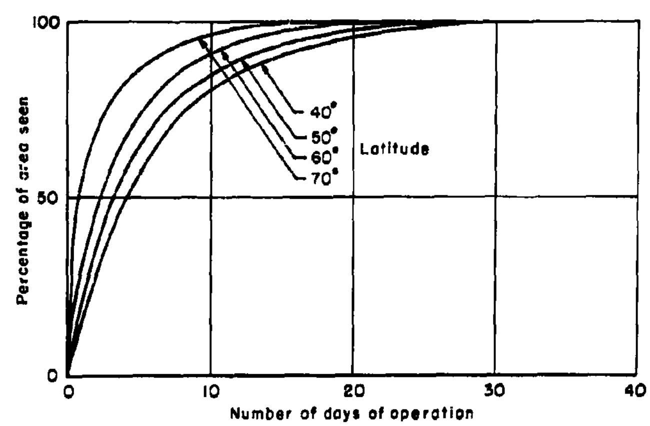


Fig. 48—Percentage of area seen as a function of days of operation

would be particularly vulnerable to political pressure. Recent demonstrations of commercial television tape recording have eased the problem of station location for a satellite photoreconnaissance facility. Storage capacity aboard the missile could be made great enough to permit large areas to be televised and stored on tape while the missile was passing over the USSR, and the pictures could be played back later to ground-communications sites. Delayed playback would allow elimination of all the foreign-based and water-based communications sites such as would otherwise be required for immediate line-of-sight

reception from the missile transmitter. In fact, it would allow the placing of all communications sites on U.S. territory, or even completely within the ZI. In the remainder of this section, on-board tape recording is assumed.

A few principles which would be helpful in making a choice of station location can be listed:

1. There should be no dependence on foreign sites or on water-borne communication facilities.
2. ZI operation would be desirable for reasons of security, weather, morale, etc., generally associated with it.
3. Short lines of communication with the intelligence center would be desirable.
4. Location far to the North would tend to maximize the potential space-to-ground communication time per day (and thus to minimize the number of sites and the on-board storage capacity required).

These principles suggest two very attractive possibilities for communications-site location. The first would capitalize on all the associated advantages and would employ two sites, one in the northwest and the other in the northeast corner of the ZI.

The other possibility would be a single site located in Alaska, northwest of Fairbanks. Such a station, because of its position near the North Pole, would be able to receive all the information that a vehicle obtained from the Soviet Union.

An Alaskan ground-communications site would be the simplest. However, the ZI-contained facility would perhaps be more attractive for actual use because of the reasons already given, and also because of considerations involving detection of the vehicle. For these reasons gross geometric aspects illustrating the capability of both possibilities are discussed here.

It is assumed that the straight line-of-sight horizon would limit communication between the missile and a site on the ground. For a 300-mi vehicle altitude, an arc of 23° along the earth's surface would be the resulting limiting distance. Figure 49 illustrates communication with the Alaskan site, and Fig. 50 illustrates communication with ZI sites. In both figures, passes of the missile are shown as lines, the arrowhead indicating the direction of the satellite's motion.

Figure 49 shows that all daylight passes of the vehicle over the Soviet Union would subsequently come within communication range of the Alaskan communications site. Communication of information from passes over western Europe could not be received until rotation of the earth had once again brought

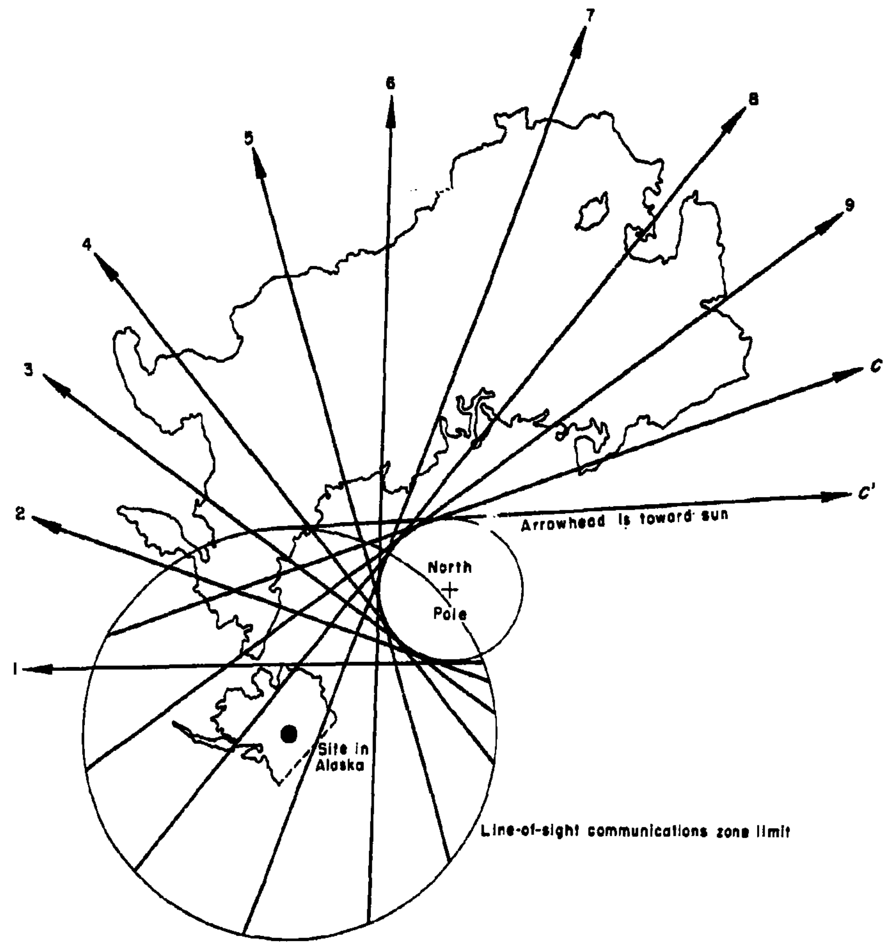


Fig. 49—Communications capability of single Alaskan site

the communications site within range of the vehicle. This would happen after a delay of 7 or 8 hr. If, during the interim, night pictures of the USSR were desired (patterns of lights should be visible), it is clear that either the western Europe pictures would be sacrificed on this day, or that slightly more than the nominal amount of tape storage would be required, and additional record-playback programming would result. Because of the proximity of the site to the Soviet Union, there is a possibility that, even with narrow-beam transmission from the vehicle, the Russians might receive signals at certain times.

Figure 50 illustrates the use of sites in the far northwest and northwest of

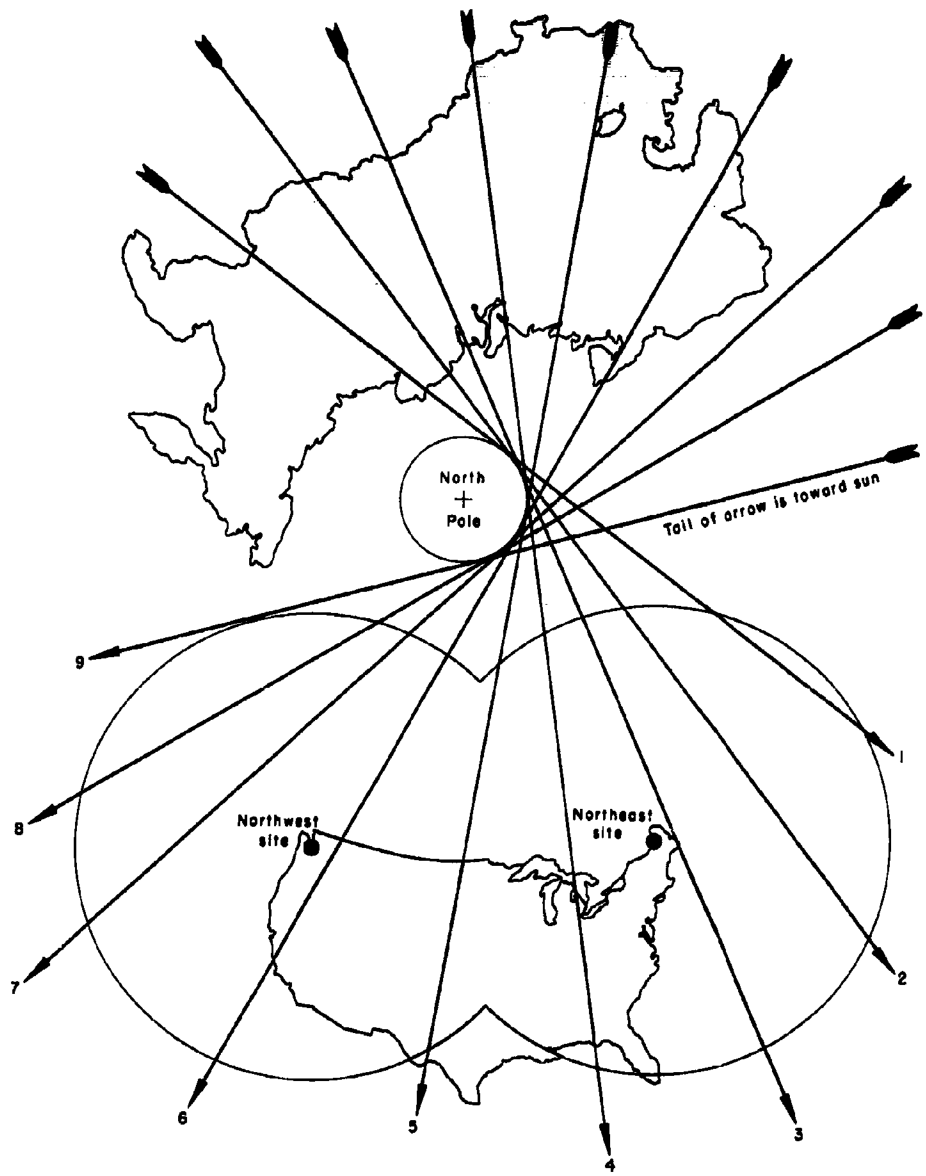


Fig. 50—Communications capability of two ZI sites

the United States to receive all communication from the vehicle. Notice that reception from daytime passes over the eastern portion of the Soviet Union would have to be delayed several revolutions before the eastern ground site could come within communication range. This difficulty could be met in either of two ways: first, by an inclusion of about 15 min of extra tape storage (above the amount assumed in weight estimates in this report); second, by the addition of a second vehicle 12 hr out of phase with the first one. The second vehicle would cover the eastern portion of the Soviet Union thoroughly, leaving coverage of the western portion to the first vehicle. Assuming either of these capabilities, the ZI installations would be very attractive from the viewpoint of practical operations.

Command Link

Acquisition. Basically a ground-tracking capability would serve two purposes. One would be to obtain raw data regarding the vehicle's motion for prediction of its subsequent passes, and the second would be to allow for acquisition of the vehicle's signal.

These operations could be performed in a number of ways. Some could be modifications of existing missile components, such as the Azusa system for the Atlas missile.

However, to make the vehicle-borne components of the tracking function as simple as possible, commensurate with the design philosophy of the payload, and to retain an adequate and reliable system, requires some thought as to the over-all requirements and as to possible operations that could be performed. These latter will be discussed below for the method assumed for this report. A chronological description will be given, beginning with the initial establishment of the vehicle orbit.

It is assumed that the television equipment within the vehicle would be designed to yield a tracking and command capability. The various operations performed by the vehicle would be preset in a programmed fashion. A program would cover several vehicle passes and could be changed at will from ground commands. Also, "fail-safe" measures would be built in for cases in which ground contact was not made for several days, etc.

It is expected that the vehicle antennas could be aimed at a ground-tracking site as determined by a precomputed program. At a given time the regular television transmission carrier frequency would be emitted, modulated by a suitable continuous-wave signal that would not impose any burden on the modulator in the vehicle. The ground antenna would be searching through a

certain solid angle of space until such time as its receiver registered this modulated signal at a predetermined level above the noise background.

At that time ground antennas would be locked onto the satellite signal, and vehicle television transmission (if any) would begin. Simultaneously the angular position of the ground-tracking antennas, as a function of time, would be recorded to allow for analysis of the vehicle orbit. Subsequently interrogations and commands would be sent to the vehicle. More detail regarding specific operations is contained elsewhere in this report.

A typical tracking sequence may be described. As has been noted earlier, the self-contained inertial guidance system would place the satellite on orbit with tolerances of ± 25 mi in altitude and $0.1°$ in azimuth. This is equivalent to an uncertainty in vehicle position represented by a spacial cylinder, 40 mi in diameter and 120 mi long, curved along the orbit path.

No tracking would be necessary during launching, although it is probable that theodolite data would be obtained.

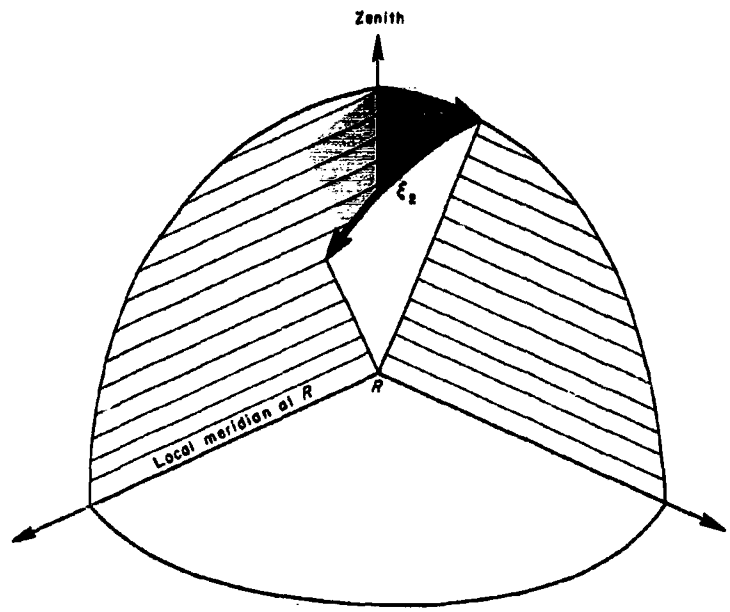
Acquiring the satellite upon passage over the tracking site after the first pass around the earth would be essentially a problem of searching over a predetermined region of space. The region is specified at any given time in terms of two angles ξ_1 and ξ_2 (see Fig. 51a), since there would be no range discrimination. To provide for direct range measurement, a transponding device would have to be placed in the vehicle, and this might be an unnecessary complication.

In general, the tracking scheme would provide a time program of angular motion of the ground antenna head centered on the expected path of the vehicle. From knowledge of initial conditions it should be possible to predict the appearance of the vehicle on a subsequent pass with a reasonable degree of certainty.[81][82] The anticipated volume of space that would have to be searched compares with tracking-angle uncertainties

$$\Delta\xi_1 = 2\tfrac{1}{2} \text{ deg} \qquad \text{and} \qquad \Delta\xi_2 = 4 \text{ deg}.$$

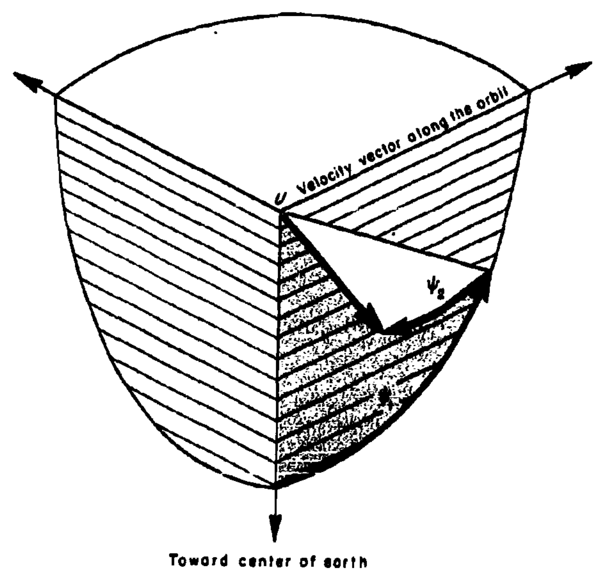
For the purpose of estimating the probability of successful acquisition, it is assumed that the vehicle would be launched so that its first passage would be directly over the tracking site. The tracking antenna would be set to look at the horizon.

A reasonable scanning program[82] would provide over 200 "looks" by the time a $10°$ elevation angle was reached. With the assumed program, a very conservative estimate of signal-to-noise ratio would be 35 db, thus assuring almost 100 per cent probability of successful acquisition soon after the appearance of the satellite on the horizon.



Plane tangent to earth at tracking site, R

Fig. 51a—Diagram of ground-tracking angles ξ_1 and ξ_2



Toward center of earth
from vehicle at U

Fig. 51b—Diagram of satellite antenna control angles ψ_1 and ψ_2

Predicting the orbit well enough to make it possible for the vehicle to be picked up after it had been out of touch with U.S.-based stations for, say, six passes, and finding a lost vehicle would comprise the two important acquisition cases. Perhaps these cases might be synonymous, because if the latter capability were built into the system, the former task could be accomplished.

A solution might lie in having two sets of limits on the azimuth angle through which search would be made by the ground antenna, assuming that scanning of the horizon would be made on a continuous time-independent basis for the relevant time periods.

Using the data gained after the first passage of the vehicle over the station, and assuming no prior data had been obtained, the uncertainty in azimuth angle (i.e., the particular point on the horizon at which the vehicle would appear) after six passes had elapsed would be 15°. It is expected that the tracking equipment described earlier in this section could be employed to handle the "lost sheep" operation, although perhaps not with the certainty of the initial acquisition.

Of course, once the orbit parameters became known, as a result of continued operation of the television system and the statistical smoothing that could be applied, the search angle would be very small. However, should the vehicle not be contacted for several days, even after these orbit characteristics had been established, a deterioration in the knowledge of the vehicle's location would accumulate with time, due to the small initial uncertainties.

The maximum angle that would have to be searched would correspond to a complete lack of knowledge of the orbit, except that it would be above a certain inclination angle. The uncertainty in azimuth (of the vehicle as it appeared on the horizon) would be equivalent to the distance between two successive passes of the vehicle. Since this distance would vary from zero near the tangent latitude to 1600 mi at the equator, the location of the ground station would have an important bearing on the difficulty of the problem. If the station were placed along the northern border of the ZI and a search were made in a northerly direction, then 25° of horizon would have to be scanned (see Fig. 52). A station in Alaska could nearly see the vehicle at the tangent latitude, so that only 2° of horizon would have to be searched.

If the vehicle was lost, its antenna would probably be pointing in the wrong direction for acquisition. In order to provide for the search outlined above, it would probably be desirable to have a "fail-safe" device built into the vehicle to point the television antenna arbitrarily forward and at a proper angle with

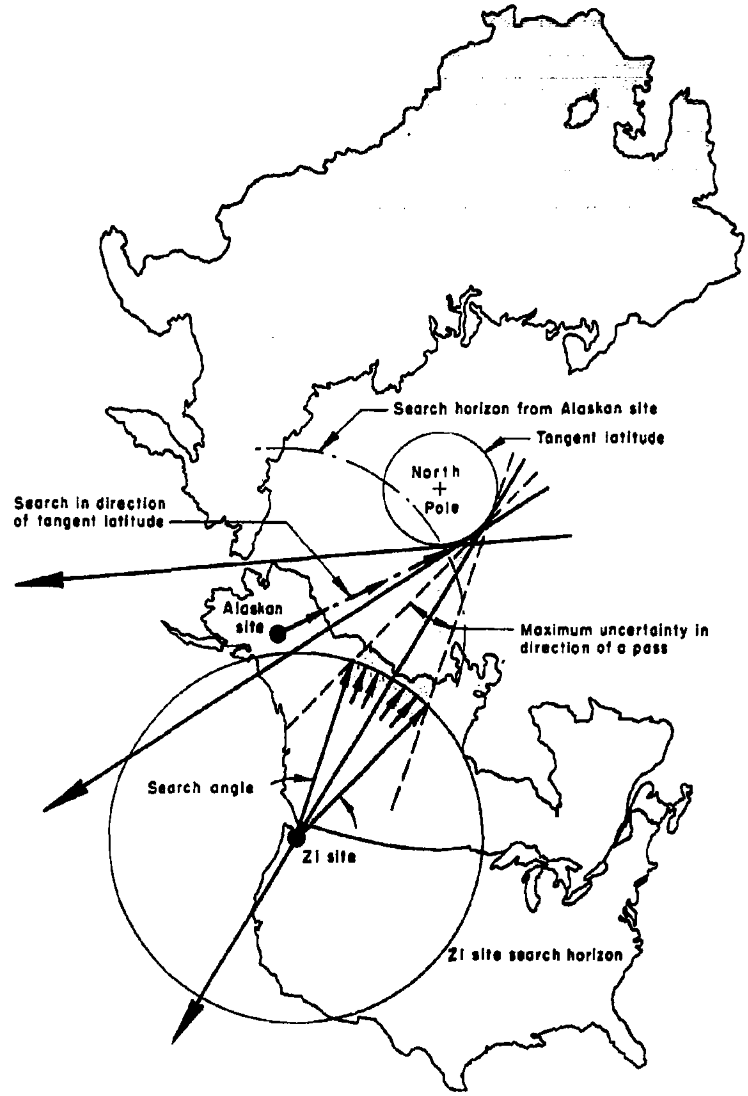


Fig. 52—Schematic showing search for lost satellite

the vertical so that the expected transmitting horizon could be seen. This antenna position would be assumed after a suitable period of time had elapsed after any contact with the ground.

At the worst, the satellite antenna would be off 12°. Since it would have a half-power beam width of 2°, probable misalignment with the ground antenna

would prevent reception of some passes. Causing the vehicle antenna simultaneously to search through 24° would alleviate this, but would permit only 2 looks by ZI-based stations and 20 looks by the Alaskan site (compared with the 200 looks for the programmed case).

Tracking and Command Equipment. Background work for some of the detail analysis of the problem of tracking the vehicle from a single ground station is described in Refs. 31 and 32. Methods are given for determining orbital parameters and predicting the satellite's position, as well as computation of antenna orientation commands from tracking data.

A ground-tracking head designed to track the vehicle successively through the zenith would be different from that of a conventional tracking radar. An arrangement which would place the pole on the horizon rather than on the zenith is assumed to be satisfactory. Figure 51a illustrates this proposed scheme, in which the fixed axis is horizontal and one other axis is perpendicular to it. Two angles ξ_1 and ξ_2 then define motion of the ground-tracking head. These are functions of known and measured parameters and enable us to predict the aiming of the ground tracker in order to pick up the vehicle on successive passes.

A choice of a lobing or a conical scanning system for accurate tracking would require detailed study. Probably a conical scan having a reasonably high rate and removed from significant frequencies appearing continuously in the television transmission would be adequate. Tracking data, together with other information on the position and motion of the vehicle, would be recorded for use in a more detailed computation of orbital parameters. As more data accumulate, the accuracy of estimates should improve and allow smoothing of data, as well as comparisons to reveal systematic errors. Many observations or long periods of observation would probably be necessary to determine the regression rate, ellipticity, and change of elliptic axis orientation. Such simple observations as transit times from several different observation posts should be of considerable help in obtaining some relatively long-term effects.

For the purpose of aiming the satellite antenna system, a search program would have to be partially precomputed, later to be supplemented by commands from the ground station. On the first pass, the program would have been determined at the time of launching. Computation of the necessary functions for aiming the satellite antenna again might be made, using angle tracking data.

Figure 51b shows the proposed vehicle antenna gimbaling scheme. A fixed axis would be placed in alignment with the vehicle pitch axis or perpendicular to the orbital plane, if the vehicle attitude were properly controlled, which, of

course, would be essential. Another movable axis at right angles to the fixed axis would permit antenna orientation to be defined again by two angles (as with the ground antenna head).

It would appear feasible to design for tracking the satellite, when not too near the horizon, with the accuracy of $1/10$ mil or perhaps better. If only reasonable care was given to the design of drive mechanisms for the tracking heads, something of the order of $1/2$-mil accuracy would be attainable. Probably such accuracy would not be required.

Launching

Ground operations, as outlined below, are considered to be feasible for the vehicle configuration assumed in this study. A substantial change in configuration or requirements might change the ground-operations concept; e.g., a smaller vehicle could be more conveniently shipped in the assembled condition, whereas a much larger vehicle might have to be assembled on the launching platform. For the present configuration, however, the firing operations might proceed as follows:

Major components of the vehicle would be assembled at the launching base, including the final (satellite) stage, the booster tank section, and the booster propulsion section. Various component and system tests would be conducted in the assembly building, both before and after assembly. Since the total number of launchings would be relatively small, it is assumed that the type of test equipment used, and the time required to assemble and test each vehicle, would be in the regime of present test launchings for missiles in the development stage. In short, the first vehicle might take a month to assemble and launch; the last one, a week.

An assembled but unfueled vehicle would be towed to the launching site on a special trailer designed to attach to the launching platform. This would be done to facilitate erection of the vehicle to the vertical position and also to effect alignment with the launching support points, as is done in the V-2 operation. The movement to the launching site, which would be 1 or 2 mi from the assembly site, would not be made until a definite launching time was established, since it would be easier to maintain the assembled vehicle in a degree of readiness in the assembly building than it would be to maintain it on the launcher for several days. A definite schedule of prelaunch operations would be put into effect, starting in the assembly building and culminating in the actual launching on the same day—provided, of course, that everything

went well. It is fully realized that such things as difficulties with guidance components could tie up operations for days or perhaps weeks.

Once the vehicle had been installed on the launcher and aligned vertically, it would be fueled and given a final check in approximately 4 to 6 hr. This final count-down would be planned to absorb minor delays so that the launching could be accomplished within a few seconds of a specified time, in order to avoid excessive corrections by the control system which might be needed to put the vehicle in the prescribed orbital plane. Failure to meet this time requirement would mean that the vehicle would have to be defueled and held over until the next day at the same solar time. Fueling would be the most time-consuming operation on the launcher. Some of the vehicle equipment would require special attention; e.g., the azimuth gyro would be monitored and adjusted within a few minutes of launching. The electronic equipment would be started, adjusted, and continuously operated, an alternative cooling system being provided during this period.

A complete test of an operating auxiliary powerplant when the vehicle was on the launcher would be undesirable, because the heavy shielding required would impede other prelaunch operations. Therefore, it would be desirable to warm up the auxiliary powerplant by alternative, external means so that it would be operating at equilibrium conditions. This would make it possible to check the power output before launching and to shut it down if necessary.

The auxiliary powerplant reactor would be started at the last possible moment to avoid radiation hazard. Prelaunch procedure would be essentially the same for various locations (except in extremely cold weather). However, for each location the launching time should be met within seconds of the specified time, and the azimuth gyro should be kept within minutes (of angle) of the specified heading.

The actual launching and positioning of the vehicle in its orbit would take place in several steps:

1. Launching and vertical ascent.
2. Inclined ascent and completion of boost phase.
3. Booster separation.
4. Second-stage main burning.
5. Coasting phase (power off).
6. Vernier burning and attainment of orbit.

All four motors of the booster would be started so as to attain the total rated thrust of 285,000 lb at the specified time for launching. The vehicle would

leave the launcher vertically under the control of its ascent guidance system, a wholly self-contained inertial system operating on a time program. As described under "Guidance and Control," page 127, the system would comprise a gyrostabilized platform which would carry the integrating accelerometers and a guidance computer provided with precomputed instructions. In essence, the system would program vehicle attitude and collect information from its accelerometers regarding departures of the actual trajectory from the precomputed standard. Under the program the vehicle would depart from the vertical about 5 sec after launching.

At the end of the boost phase, about 125 sec after launching, the vehicle would be inclined approximately 12° from horizontal at an altitude of 153,000 ft, a velocity of 11,500 ft/sec, and a ground range of 65 n mi from the launching point. Separation of the booster from the second stage and initiation of second-stage burning would take place almost simultaneously, after which the main motor of the second, or satellite, stage would burn at a rated thrust of 36,000 lb for approximately 148 sec. At the end of second-stage main burning, the vehicle would be inclined approximately 2° from horizontal at an altitude of 350,000 ft, a velocity of 26,700 ft/sec, and a distance of 475 n mi (measured along the ground) from the launching point. Visibility permitting, the vehicle could probably be tracked optically up to this point. Cut-off of the second stage would be commanded by the on-board computer when the variations of the actual trajectory from the standard were in a proper combination to ensure that the vehicle would be vectored into the desired orbit. In this way the effects of performance variations on the ultimate orbit could be minimized. From the cut-off point, the vehicle would coast with zero thrust up to an altitude of 300 stat mi at a ground range of some 7500 n mi (8500 stat mi) from the launching point. The guidance unit, meanwhile, would orient the vehicle so that, upon coasting onto the orbit at a time computed on the basis of cut-off conditions, the vernier motors would be in position to add their final thrust tangent to the orbit, bringing the speed up to the satellite velocity of 25,028 ft/sec. Then, about 2000 sec after launching, these small motors would be shut down and control would be taken over by the orbital attitude system.

THE SATELLITE VEHICLE

Having discussed the various functions envisioned for Feed Back, as well as those associated with its operation, it is now desirable to look at the specific vehicle and the constraints under which it operates. Vehicle configuration will

be described first, followed by discussion of guidance and control, auxiliary power supply, and environmental problems.

Configuration

As seen in Fig. 4, the over-all configuration would be a two-stage ogive-cylinder-boattail combination, attachment of the two stages being at the aft end of the second-stage propellant tanks. The covering of the second-stage powerplant compartment would serve to transmit the axial acceleration loads during boost and would be integral with the booster. Upon separation of stages, this covering would be carried away with the booster, thereby uncovering the equipment housed in the second-stage rocket-powerplant compartment. This would include, in addition to the rocket motors, the television equipment and the attitude-control sensing system. Thus, the television scanner, the attitude-control horizon scanner, the transmitting antenna, and the electronic cooling radiators would be exposed to outer space by this one operation (see Fig. 53).

The nose would be a right circular ogive of 2½ caliber and would fair into the 9-ft-diameter cylindrical section of the vehicle. The after end would boat-tail to approximately 8.2 ft in diameter.

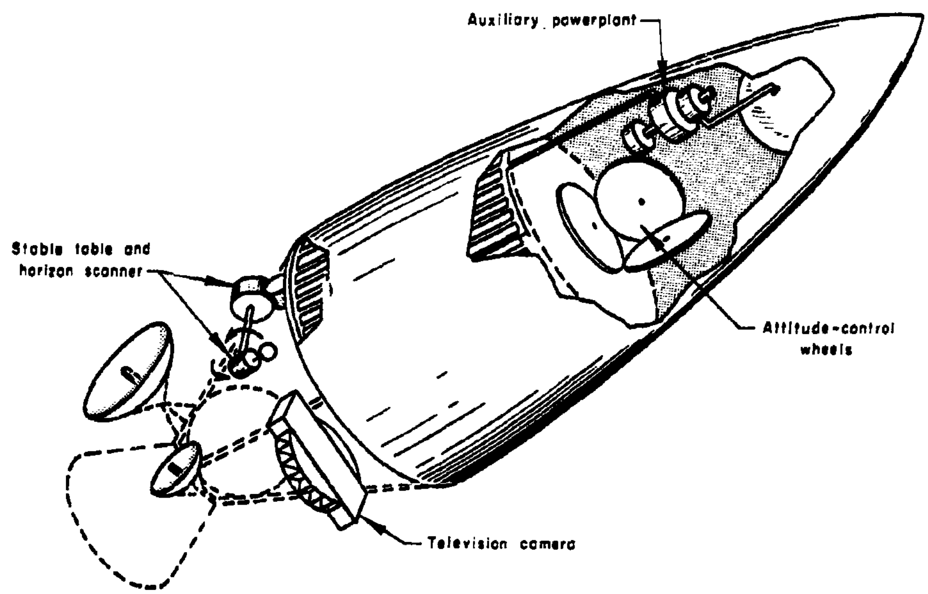


Fig. 53—Schematic of vehicle passing overhead

In line with the desirability of straightforward development, coupled with reliability (see "Reliability," page 142), conventional construction (similar to that in missile production today) is assumed for both the satellite and booster stages. The use of pressurized nonintegral (with vehicle skin) tanks, to transmit primary bending and compression loads in both stages, would allow full use of the aluminum-alloy, room-temperature, material-strength properties. In general, internal structures would be aluminum. The external skin would be of stainless steel because of the high skin temperatures generated in the ascent.

Determination of the vehicle size and weight is described in Vol. II. At launching, gross weight of the vehicle would be about 178,000 lb; and dry weight, 13,360 lb. The satellite stage would have a gross weight of 22,500 lb at stage separation and an orbiting weight of 4500 lb. The over-all length of the vehicle at launching would be 81 ft and the length of the satellite stage would be 28½ ft.

The amount of fuel consumed would be such that vehicle weight would decrease during each stage of burning by about 80 per cent. Although a lighter vehicle could be built, using higher-performance propellants, emphasis has been placed on the relatively simple system, liquid oxygen and gasoline, in order to derive maximum benefits from current high-performance missile projects. The present state of the art of large gasoline–liquid oxygen rocket motors for other programs would make such fuel the best for use in the satellite. Further, vehicle weight and size, based on this propellant system, would be such that two of the 120,000-lb units being developed by North American Aviation, Inc., for use in the Atlas Project could be used as the main units in the booster. In addition to these main-thrust units fixed to the structure, two smaller, gimbaled units of about 22,500 lb would be used to control the vehicle during the first stage of burning. A single fixed-thrust unit of about 36,000 lb would be used during the main burning of the second stage. In addition, four very small units with thrust control would be provided to furnish accurate increments in velocity and attitude rate for the thrusting which would be needed at the end of the ascent coasting period.

Guidance and Control

Ascent. Both the plane and shape of the orbit can be dictated by the ascent-guidance system. Tolerances on orbital inclination and altitude have been discussed under "Choice of Orbit," page 104. These considerations, together with weight and reliability, would govern the guidance design specifications.

A system has been devised which demonstrates the feasibility of meeting the design requirements with comparatively simple equipment. Details and analysis are presented in Vol. II, which also includes a study of performance over a representative ascent trajectory. The major features of the system and salient results of the analysis are summarized below.

Ascent-guidance equipment would be of a wholly self-contained inertial type, comprising a platform stabilized by three 1 deg/hr gyros and carrying three $\frac{1}{1000}g$ integrating accelerometers, an electronic analogue computer, and associated conventional servo controls. Power would be provided by the auxiliary powerplant, while control over the vehicle during the propelled portion of the ascent would come from gimbaled auxiliary thrust motors. Roll control would be provided by differential motion of these motors.

The platform assembly would occupy 2 ft^3 of space and would weigh about 50 lb; the computer would require an equal amount of space and would weigh 60 lb. A first-stage servo system would weigh around 100 lb. The second-stage gyro would weigh about 50 lb.

The stabilized platform would serve as a reference from which measurements of vehicle attitude and motion could be made. On this basis, roll, pitch, and yaw would be discriminated. Three accelerometers, each at right angles to the others, would be used. Lateral deviation of the vehicle from the programmed position would be detected by the lateral doubly integrating accelerometer. The yaw servos would continually drive this deviation toward zero, so that the orbital plane would be established with the required accuracy. The guidance problem would thus be reduced to one of properly vectoring the vehicle velocity in the established orbital plane.

The method selected for vectoring the velocity would be a modified time-programmed control. A theoretical trajectory would be prepared on the basis of flight-mechanics considerations and estimates of thrust motor performance and of aerodynamic and other forces. Pertinent data would be recorded and fed into the guidance computer as a time program. During the two boost stages of ascent, the pitch would be time programmed according to the standard trajectory. In general, the thrust and other forces, and hence the vehicle motion, would differ from the estimates. The computer, reading the accelerometers, would keep a running record of the difference but would command no guidance or thrust changes from the standard program. As the end of the second stage was approached, the computer would compare its current values of velocity, altitude, and path angle deviations with recorded functional relations between

these variables, which would yield the desired orbit parameters. It would not be necessary for all the deviations to be zero, but only for them to be properly related at thrust cut-off to ensure coasting up to the desired orbit. When a correct combination was indicated, and one would be reached for reasonable magnitudes of variation, the thrust would be cut off and the vehicle would enter the coast phase of the ascent in error only by the system errors, which would be shown to be small, even though the actual ascent might have varied considerably from the predicted trajectory. This is illustrated in the table, below, which compares the magnitude of the variations near cut-off with the error in the computer knowledge of them for the example presented in Vol. II, Ref. 31.

Item	Standard	Actual	Variation	Computer Error
Velocity, ft/sec	26,187.2	25,896.8	290.4	−17.2
Path angle, radians	.03285	.01329	.01956	+.00114
Altitude, ft	354,984	288,760	66,224	+5,833

The major task of the guidance system would be accomplished when the vehicle was properly vectored into the coast. During the power-off (coasting) portion of the ascent, attitude would be maintained by the same system as that used in the orbit (see next section). It would remain to apply the trim thrust when the orbital altitude was reached at the top of the coast. Again, the coast time, coast angle, and trim velocity increment would differ from standard values in relation to the thrust cut-off deviations. The computer would be apprised of the necessary changes, however, which it would command to the system in order to schedule and orient the final burst of thrust. While the trim velocity would not need to be applied with extreme precision, it would probably be advisable to use one of the accelerometers to measure it rather than to rely on mere timing of the burst thrust.

The boost stages would involve a transition from the rotating earth framework into the "fixed" orbit plane in addition to the velocity vectoring in that plane. The gyro reference could be either earth-fixed or inertial, the choice depending on the ease of alignment and of instrumenting the transition. Earth-rotation initial velocity and Coriolis and aerodynamic forces associated with the earth's reference frame would all enter into the trajectory programming but would not change the basic component requirements outlined above. Taking off from the earth's surface, which of course has motion normal to the orbit plane, would result in a curved boosting path noncoplanar with the orbit. Thus,

programmed variations in yaw and roll would have to be included with the pitch change schedule during the thrusting period.

Work of the ascent guidance system would be completed with the application of the trim velocity. The space craft thereafter would freely pursue its orbital path as a true satellite. Some components of the ascent guidance system would be taken over for use by the orbital attitude-control system, which is discussed below.

Orbit. Knowledge and control of the vehicle orientation relative to the earth is important for a number of reasons. An auxiliary powerplant would require a heat sink for its operation and must radiate excess heat in predetermined directions. The vehicle would have to be sufficiently stable so that motion during exposure of each picture would not cause blurring and so that the desired picture-scanning pattern would be maintained and a full 400-mi-strip width realized. Attitude departures from the vertical would have to be kept small in order to minimize errors in locating targets when the reconnaissance pictures were used for mapping. An antenna would have to be oriented for communication with the ground.

There are three factors which would affect the attitude of the satellite: the nature and magnitude of torques perturbing the vehicle from its desired attitude, the errors of a sensing system provided to determine the amount of deviation existing at any instant, and the characteristics of the system employed to restore attitude deviations to zero. These factors are considered in turn below and are based on the perturbation torque analysis, recommended attitude-sensing system, and recommended attitude-control system presented in Ref. 33, as studied by North American Aviation, Inc.

Perturbation torques on the vehicle could be considered as being of three types: those which would be random in impulses, those which would be constant persistent torques, and those which would be oscillatory with a frequency equal to a multiple of the orbital frequency. Random torques would arise from meteorite impacts and the starting and stopping of rotating machinery within the vehicle. Constant torques would arise from eddy current drag in the magnetic field of the earth, from radiation incident on or emitted from the satellite, and from the gyroscopic interaction of the uniform pitch rotation of the vehicle (necessary to keep a specified side always toward the earth) with angular velocities of certain internal rotating parts. Periodic torques would arise from gravitational (and possibly magnetic) perturbation forces. No complete analysis of perturbation torque can be given until the detailed satellite design is much further advanced than at present. However, the analysis of

Ref. 34 indicates that rotating parts within the vehicle might produce the principal torque perturbations, of the order of 1000 to 10,000 dyne-cm, and that the magnitudes of the other possibly significant perturbation torques would be in the range of 10 to 100 dyne-cm. Such numbers would be important in choosing the type of attitude-control system described below.

It is necessary to sense attitude deviations before they can be corrected. A number of systems have been considered, but the following seems to be adequate and to offer certain advantages. A gyrostabilized platform would be maintained within the vehicle to provide a vertical reference. The pitch gyro would be continually torqued to yield a constant instantaneous vertical reference (and thus pitch rotation with respect to inertial space). A method for compensating for the torque biasing reaction on the vehicle would be that of periodically flipping the gyro back an integral number of revolutions corresponding to the number of times the vehicle circled the earth. Because of gyro drift and incorrect gyro torque bias levels, such a platform would ultimately depart from the vertical if left to itself. However, an optical scanner system could be introduced, as illustrated in Fig. 54, to establish the vertical relative

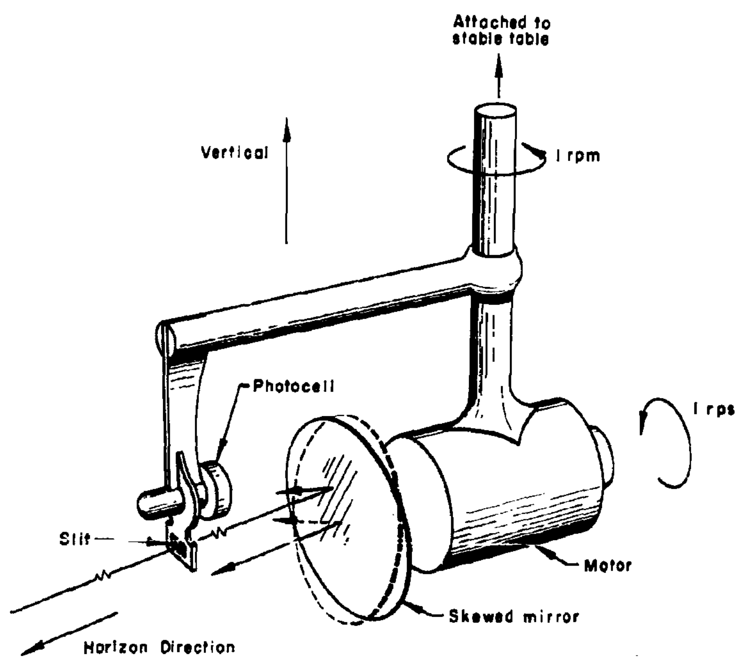


Fig. 54—Schematic of horizon scanner

to the disk of the earth by optical observation of the horizon every time the vehicle passed over the daylight side of the earth. The scanner could be used to monitor the gyro system, providing periodic compensation of drift. The gyro system, in turn, could be used during the same period to smooth out the high-frequency irregularities in the scanner signal that would arise from clouds and mountains. Thus, the stabilizing platform with horizon scanning monitor would offer advantages over the separate use of either system.

When the vertical had been established and stabilized, it would be possible to sense yaw by means of a device operating on the same principle as the gyro-compass. An azimuth gyro, suitably constrained, would be mounted on the stable platform. As the satellite moved around its orbit, this gyro's spin axis would tend to align itself with the normal to the orbit.

Of the feasible methods of controlling attitude, the one appearing to require least development is a scheme shown in Fig. 55 which depends on inertial reaction. Three flywheels would be provided in the satellite, their axes respectively aligned with the three principal vehicle axes. To turn the vehicle through a certain angle, the appropriate flywheels would be merely rotated through a suitable angle with respect to the vehicle frame, inversely in proportion to the relative moments of inertia of the vehicle flywheels.

The actual control operation would begin with the reception of attitude-deviation signals from the sensing system. These in turn would be introduced into a control computer (required because all three wheels would generally have to be torqued by the desired control). If the sensed deviations approached zero, the torques on the flywheels would also be reduced to zero. The actual control equations are discussed in Ref. 34, where the speed of vehicle response desired, the tolerable steady-state deviation, perturbation magnitudes, and the random noise arising from the sensing instruments are all considered. Detailed design studies indicate that the entire orbital attitude-sensing and control system can be achieved using components and techniques that will not require elaborate research and development.

Auxiliary Power Supply

In this section a representative auxiliary powerplant to furnish electric power to the payload will be discussed. A water-moderated reactor to produce heat to operate a closed-cycle mercury turbine-generator unit will be described. Implications of this choice as well as enumeration and evaluation of alternative cycles and heat sources will be given in Vol. II.

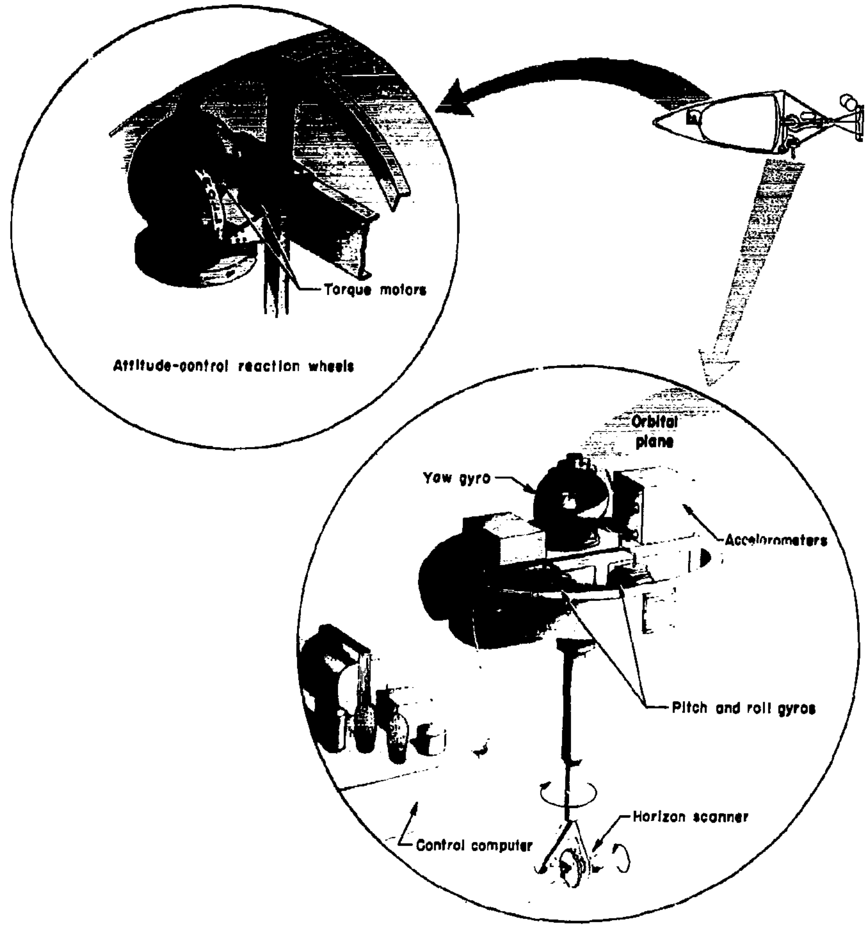


Fig. 55—Schematic of attitude-control system

Our philosophy regarding the auxiliary powerplant is as follows. Each satellite vehicle would be costly enough to warrant additional engineering cost to achieve long-term (many months) operation of components. Even simple payloads for useful military purposes would require about 1 kw of electric power, even though special consideration was given to reducing power requirements as much as possible, as, for instance, by transistorizing circuits. Mechanical gadgetry and other complexity would have to be held to a minimum, and components or cycles requiring phenomena not amenable to simulation for test purposes should be avoided, if possible.

The only power source of immediate promise at the present time would be a nuclear reactor. Chemical sources or an open-cycle radioisotope-heated powerplant would be too limited in duration for use. Solar energy, while independent of time, would not be sufficient in magnitude (by a factor of 10) unless prodigious mechanical devices were incorporated. A radioisotope heat source for a closed-cycle engine would be quite expensive and has been temporarily abandoned in favor of the nuclear-reactor source. Some of these rivals probably warrant further exploration for the benefit of future generations of satellites.

Once a nuclear reactor with a closed-cycle engine had been chosen, other effects would become apparent. To review thermodynamic constraints, it will be recalled that a closed-cycle powerplant (wherein the working fluid is used over and over again) must incorporate a cooler to restore the working fluid to its original state each time it starts through the cycle. In the preceding section it was mentioned that heat must be dissipated by radiation. Thus a skin radiator would be needed for the auxiliary powerplant.

If a useful amount of heat is to be given off, radiator temperatures of several hundred degrees Fahrenheit are indicated. In turn, a fairly high source temperature would be needed to attain reasonable powerplant efficiency; i.e., source temperatures from 900° to 1300°F could be shown to be proper.

Therefore, a new regime of nuclear power reactors is needed, hitherto undeveloped and representing one of the clear-cut research efforts that can be made in connection with Project Feed Back. Various studies lead us to believe that the development is feasible and reasonably inexpensive.[36–39]

As will be shown in Vol. II, once a nuclear reactor is predicated as a heat source, an almost unlimited amount of power can be derived from it at a constant temperature. The engine components themselves are quite on the "minimum gauge" side of reasonable design. Thus, the only real deterrent to acquisition of power outputs far in excess of 1 kw is that of sufficient radiator area. The vehicle employed as typical in this report would have about 200 ft^2 of skin available for these purposes, or probably enough to allow production of 3 kw of electricity.

Should more area be required, another 300 ft^2 could be added* for an equivalent payload-weight increase of 300 lb (about 1 lb/ft^2). Beyond this point, skin area would cost proportionately more—about 2 lb/ft^2. Thus, for a price, a capacity of several more kilowatts could be obtained. Further, a somewhat con-

*This is the skin covering the rocket-motor section of the final stage, which is carried away with the booster upon stage separation.

servative cycle efficiency has been assumed. By increasing the efficiency, the system output could likewise be increased for a given radiator area.

A schematic of the auxiliary powerplant is shown in Fig. 56. A water-moderated reactor of about 2 ft in diameter would be used. It would produce 80 kw of heat. Of this, 4 kw would go into the moderator, which would be separately cooled and maintained at 300°F, a pump and radiator being provided for the purpose.

The heat-producing element would be a 200-ft-long, ½-in.-diameter steel tube coated with U^{235} in oxide form, comparable to a monotube boiler. Liquid mer-

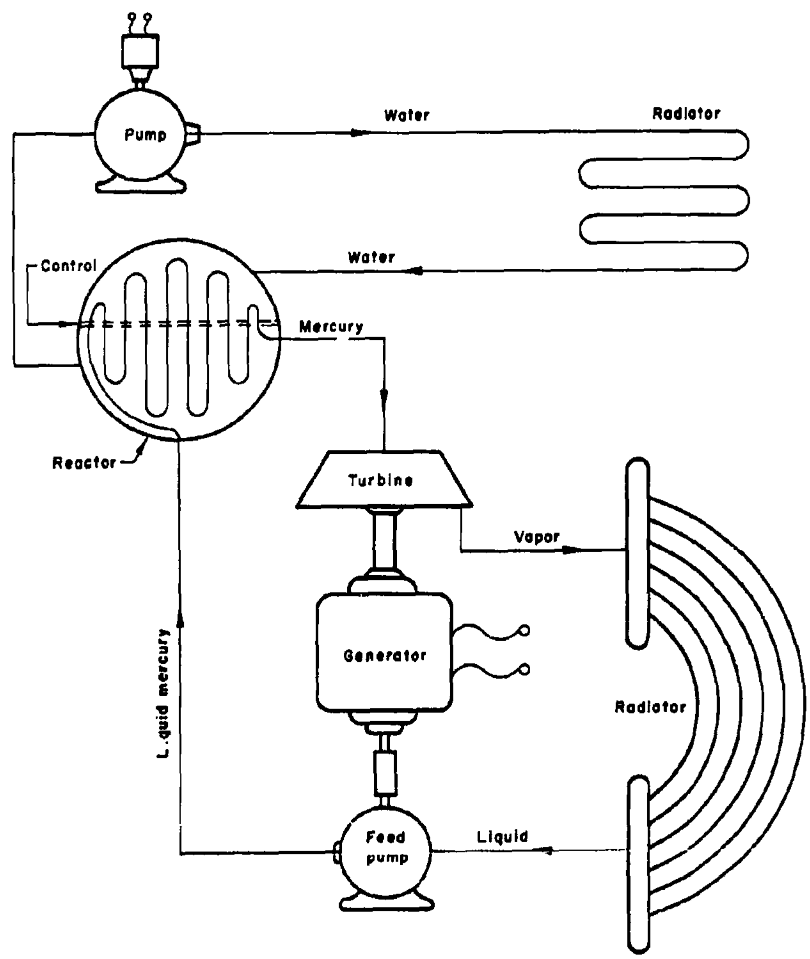


Fig. 56—Schematic of auxiliary power supply

cury would be passed into this tube and heated to gas at 1000°F, for which purpose the tube wall temperature would be maintained at 1200°F. Most of the 80 kw produced by the reactor (76 kw) would be transferred into the mercury working fluid. To maintain this large ratio of heat transferred to the mercury in preference to the water moderator would require insulation between the tube and the water. This is discussed further in Vol. II.

Mercury vapor would be expanded through an impulse turbine which would drive both the feed pump and generator. About 72 kw of the heat added to the working fluid by the reactor would have to be disposed of by the radiator. Slightly more than 76 kw of heat would be contained by the gas entering the turbine (0.05 kw), since it would include, as well as reactor heat input, the heat equivalent of work added to the fluid by the feed pump. This latter amount would recirculate constantly between the feed pump and turbine. Figure 57 illustrates the apportionment of heat between various powerplant components. The eventual output of 2 kw is seen.

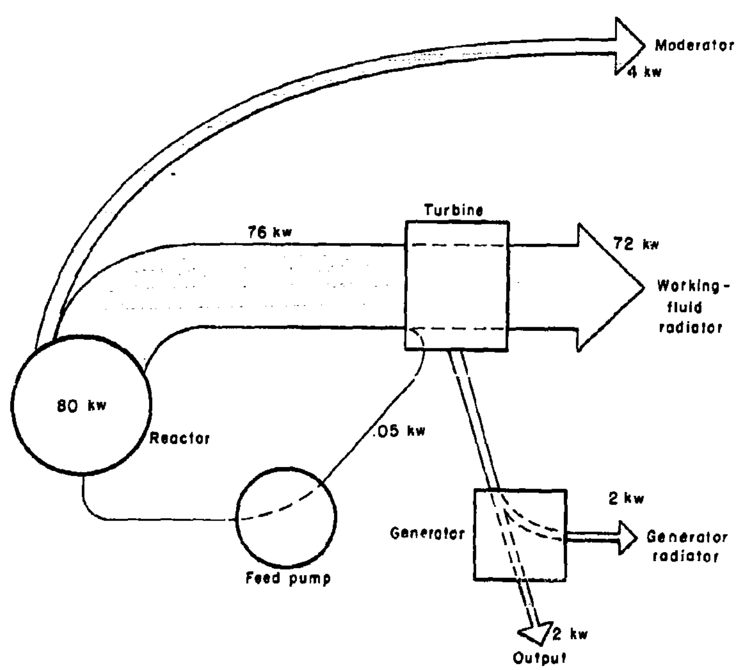


Fig. 57—Heat-balance diagram for auxiliary powerplant

It is expected that the auxiliary powerplant would be designed to operate at a fixed point, i.e., input and output would be constant and all other conditions would be very nearly constant. This would alleviate control problems, increase reliability, and also improve design aspects; e.g., it would be possible to design the turbine at the maximum efficiency point.

The powerplant would be started on the ground (using another heat source) and operated for some time prior to firing to establish equilibrium heat conditions. Just before firing, the reactor would be cut into the circuit. Useful power would then be produced during ascent to operate payload accessories. A more detailed discussion may be found under "Launching," page 123.

Over-all auxiliary powerplant weight was found to be about 450 lb, for the system described above, to produce about 1 kw. An additional output of 1 kw would require an additional 50 lb, and this allowance was included in the weight summary for the vehicle.

Environmental Problems

Ascent. During the boosting period, conditions of high acceleration, vibration, and aerodynamic heating would arise. These would be essentially the same as those encountered by any high-performance rocket vehicle. However, for the satellite, special consideration would have to be given to the relation between these effects and the high reliability demanded of the television system. Figure 58 gives curves showing the expected variation in temperature for various parts of the vehicle. The influence of these temperatures on structural design and choice of outer skin material is given in detail in Vol. II. It should be noted that no new and unusual problems are anticipated.

The computation of skin temperatures included an accounting for the heat dissipated by the auxiliary powerplant radiator, full power being continuously produced. In reference to Fig. 58, it will be seen that, in this region of the skin, the temperature stays fairly constant and at about the orbital operating value.

Cooling radiators for the electronic gear would not be exposed until the end of the coasting period. Thus, for a 5-min period an alternative cooling means would have to be provided, e.g., evaporation of several pounds of water.

Orbit. The orbital environment surrounding the vehicle components would have considerable influence on their operation. Parameters characterizing environment, as well as phenomena within and without the vehicle affecting these parameters, and the extent to which we believe they could be controlled, will be discussed here.

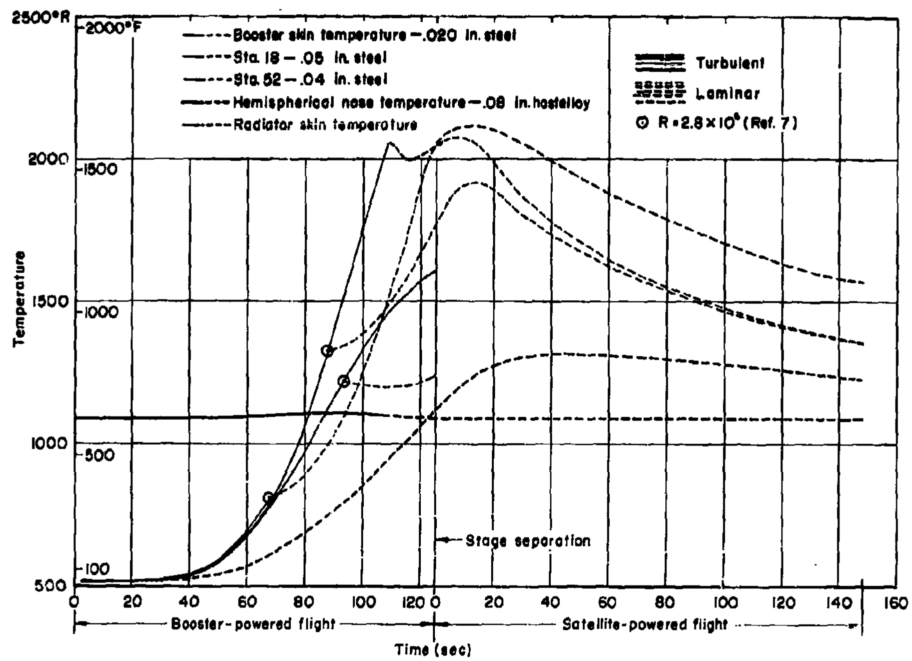


Fig. 58—Skin temperature of a satellite during powered flight (1500-lb payload; 300-mi-altitude orbit)

First we shall discuss those things that typify environment: temperature, atmospheric density, gravitational force, etc. Many of the effects can be written off as unimportant, as will be seen in the following discussion. Conversely, many apparently negligible phenomena will cause concern in design.

Atmosphere is virtually nonexistent: At a 300-mi altitude the pressure is about 10^{-12} sea-level atm, and the density is believed to be around 10^{-14} lb/ft^3. The corresponding air temperature (energy of individual molecules) is 2200°F, although this quantity has little meaning, since negligible heat could be transferred from such a hard vacuum to the vehicle. By the same token, heat originating in the vehicle (from the powerplant reactor) and that arising from solar heating would have to be dissipated by radiation from the skin. Thus the temperature of the vehicle skin at any point would satisfy a condition of equilibrium between heat influx and radiation to space. This, in turn, would be a function of thermal emissivity of the surface. Figure 16, Vol. II, page 26, gives a plot of surface temperatures at various points around the vehicle (for no dissipation of internal heat).

Naturally, the temperature of the interior of the vehicle would tend to establish itself intermediately between extremes of the skin temperatures, except where components within the vehicle produced heat derived from other sources. In cases where conductive or radiative heat rejection from components to the skin was insufficient, a forced-feed cooling system with a skin radiator would be required. Such cases would include the auxiliary powerplant and most electronic equipment. A discussion of specific cooling systems may be found in Vol. II.

The fact that the environment is a virtual vacuum alleviates any problems of oxidizing and corrosion. However, containment of any gas would necessitate prodigious design and prelaunching checks for leakage. Furthermore, some combinations of gases and metals would result in very high diffusion rates. A computation of the diffusion for a number of these combinations may be found in Vol. II.

Electronic equipment is subject to arcing and other electrical phenomena when in an environment of reduced gas pressure. This pressure is somewhere between that of sea-level atmospheric pressure and a vacuum. If sea-level pressure were to be employed in the containers surrounding the electronic equipment, then a slow leak would eventually create a low pressure of a dangerous nature. A preferable solution would be to evacuate the containers below this critical pressure region before starting the equipment on the ground.

Although the orbital ambient atmosphere has a very low density, it is still comprised of a number of particles, namely $10^{11}/ft^3$, about one-third of them being ionized. Further, there are many free electrons, both electrons from this ionization and albedo electrons from the lower atmosphere. The vehicle would thus be immersed in a conducting medium, and the prospect of its building up a surface change over a period of time would not be great. Therefore, sufficient interaction of the vehicle with the earth's magnetic field to cause orbit perturbation would not be very probable.

Solar radiation energy received by the vehicle would not be much greater than at the earth's surface. The increase would largely be in the ultraviolet frequency range, a component that is filtered out by the ozone layer on its way down through the lower atmosphere. The effects of solar radiation on the vehicle from a materials standpoint should be small, since only metal parts would be exposed.

Energy received from the sun and that radiated away from the vehicle would give rise to torques, due to radiation pressure. Although these torques would be very small, it is of interest to note that they would be significant when attitude

control was considered. The orbital control section of Vol. II gives detailed information on this and other comparable sources of perturbing torques tending to change the vehicle's attitude.

Cosmic rays at a 300-mi altitude differ from those at ground level. At this altitude they are almost all primaries, i.e., protons (hydrogen nuclei), alpha particles (helium nuclei), and a few nuclei of heavier atoms. These particles have velocities approaching the speed of light and thus are very high in energy. They initiate in the appreciable atmosphere showers or cascades which are comprised of nuclear fragments, mesons, and gamma rays.

Showers, however, would tend to occur at levels below the vehicle. The effect of cosmic rays on the vehicle would probably be negligible, since the over-all flux of the primaries themselves would be small. It has been estimated that this flux would be of the order of 2 particles/cm^2-sec. An ionized track left by a cosmic primary through, say, the photocathode surface of the Image Orthicon camera would contribute somewhat to the over-all noise level, but only for a microsecond or so.

For a different reason the flux from the auxiliary powerplant reactor would also be of small consequence in the vehicle design. Because neutrons are uncharged, ionization of material would not be a problem. However, permanent material damage caused by the neutrons would be of concern. At 1 m the neutron flux would be 1.5×10^{10}/cm^2-sec and the hard gamma flux would be 5×10^{10}/cm^2-sec. These would probably be within the tolerance limit for nearly all electronic equipment, although this point would need checking. Protection of the Image Orthicon camera tube target and the photocell of the horizon scanner of the altitude control against neutrons is believed to be necessary; a few pounds of borated paraffin should suffice for the purpose. Transistors will not tolerate nuclear radiation above habitable levels, and these components, if used, would probably have to be heavily shielded.

Lack of a strong gravitational field forebodes trouble in cases where change of phase, convection, and bubble formation are desired. The vehicle would be maintained with the bottom side always facing the earth. Therefore every part of the vehicle would revolve around every other part once every 1½ hr (inertial space reference frame). This rotation would institute, at a point 10 ft from the center of mass, an acceleration field of $0.4 \times 10^{-6}g$.

In many instances it cannot be established definitely whether or not a process will work; and, further, no long-time "gravity free" test can be conducted, short of launching a satellite. For this reason it is best to avoid designs depending on

change of phase, etc. It would be nice, for example, if a gas powerplant cycle could be used in place of a vapor cycle, since the former would not involve change of phase, and no uncertainty from the above phenomenon would exist. However, small gas turbines having efficiencies of 80 per cent or more would have to be developed. Using expedients such as monotube boilers would alleviate problems of boiling under gravityless conditions. Furthermore, if such a boiler could be made to work upside down (i.e., against gravity), then perhaps its gravity-free operation would be assured.

At the present time, meteors, including their energy distribution, frequency of occurrence, and penetration effects are the biggest unknown quantity. It is believed that only one penetration of the vehicle in a period of 1 year will occur, and this has only a small (10 per cent) probability of putting the vehicle out of operation.

However, should the number of meteors computed err on the low side by a couple of orders of magnitude (which is not unreasonable, considering the nature of the computation involved), or should some of the dust-size particles be capable of greater penetration than would be consistent with present theory, then serious consequences might result. Further discussion of the meteor problems may be found in Vol. II.

The earth would shield the vehicle from meteors from below, so that protection of the optical system would not be necessary. In any cases in which additional protection would be desirable, the structure could be laminated, with gaps between the material, or the use of thicker sections could be employed.

PROGRAM CONSIDERATIONS

In addition to studies of technical feasibility, there has been a continued appraisal of other problems which would attend a full-scale development of the Feed Back project. This appraisal has covered some of the philosophical and policy problems of such a program, as well as the more straightforward considerations of cost, schedule, and facilities requirements.

Principles and Constraints

A guiding precept in the Feed Back program should be high reliability of vehicle-borne components coupled with low development time, wherever possible. The most important goal of the program should be the acquisition of initial terrestrial reconnaissance data, and the course of development to attain this

objective should be plotted accordingly. All other uses of the satellite, including even large-scale detailed reconnaissance, are by-products of this first operation.

Of course, there will be many instances where planning can profitably include considerations of alternative and future applications. However, in no case should the initial objective be compromised. If it should appear desirable to use a launching platform made out of optically polished East Afghanistanian marble, this should be done without qualm, since the unit cost would probably be negligible compared with that of the over-all system or indeed the value of the strategic advantage to the United States contributed by the pioneer reconnaissance data.

Reliability. A television reconnaissance satellite would be a complex device which would have to operate unattended and continuously over a long period of time (as much as a year). Reliability is a legitimate subject for concern in considering Feed Back's operational usefulness, and initial recognition of the unusual reliability demanded of satellite components can be an important step toward eventually meeting those demands.

The question of whether it is feasible to develop and produce a Feed Back vehicle of satisfactory reliability has been answered affirmatively,[14] based on examination of the most critical (electronic) vehicle-borne components and on comparison of their complexity and required operating time with the failure rate of the most reliable electronic components produced to date.

As an aid to understanding the over-all problem, it is desirable to review the satellite components and operating environments.

In the preorbital period the satellite would encounter axial accelerations of $10g$ or less, vibrations arising from the propulsion system and from flutter of the aerodynamic surfaces and structure, possibly slight shocks at stage separation, and heating from skin friction, from the propulsion systems, from electronic elements, and from the auxiliary power supply. This entire period would last for half an hour, most of this time being spent in coasting to the orbital altitude.

The orbiting phase would be marked by mild environments and long duration. Here the main environmental factors would be heating from vehicle components and the sun, nuclear radiation, and possible vibration from moving parts such as pumps, motors, and generators.

As presently conceived, all the payload equipment would be started before launching and operated thenceforth. It may be assumed that failure of any of these components would terminate or grossly reduce the satellite's usefulness.

Types of reliability problems for Feed Back are different from those associated with standard military items. Rough handling, climatic extremes, maintenance and operation by unskilled personnel, or ballistic shock would not occur. The requirement of long-time unattended operation is particularly stringent and is the major reliability problem. For a year's continuous operation with 100 tubes, a satisfactorily low probability of failure for this equipment requires that the tube failure rate be less than one in 10^6 to 10^7 tube hours, a reliability which, though exceedingly high, has been reached in at least one instance.[40][41] (These figures assume that the tube failures are independent; for a further discussion of electronic equipment failure, see Refs. 42 through 44.)

Included in the problem of achieving satisfactory unattended operation of the satellite over a long period of time is achievement of a high degree of stability and resistance to wear in the components. Stability is a function of the precision of the mechanism and the tolerance limits on performance, the most stable operation being one which combines high precision with wide tolerances.

The main difficulty in obtaining high stability is the fact that phenomena which are usually neglected now become significant. For example, most materials are inherently subject to progressive changes which may become important over a long period of time. Progressive changes due to long-term deterioration of materials in the moderate nuclear radiation field of the auxiliary powerplant reactor must be considered.

Strains and distortions of fabricating and mounting must be substantially eliminated, or they will give rise to long-term changes. Seasoning by means of thermal cycling may be useful in this connection. System design can probably do much to alleviate component requirements and thereby promote stability.

The reduction of mechanical wear is mainly a problem of choosing tough materials: tungsten carbide, boron carbide, nitrided steel, synthetic rubies or sapphires. The use of a dry lubricant such as molybdenum disulfide will assist in many cases. The effects of wear can sometimes be decreased by using geometries which, through symmetry, retain their positioning despite wear (e.g., a cone-shaped bearing).

Provision of duplicate, or redundant, components for the purpose of increasing reliability may be useful in the ground system, to prevent the unnecessary loss of information. The weight penalties for duplicate components, together with the need for switching from failed to unfailed components (including a decision-making device), make this method undesirable for airborne equipment. For such reasons redundancy has not been used to any extent in the design

of guided missiles. On the other hand, certain lighter components in the satellite vehicle may prove attractive subjects for duplication, provided they are amenable to switching to alternative components by means of the simple command system used for the vehicle. In fact, in the standard television system assumed in this report two Image Orthicon tubes have been employed. Failure of one would still allow half of the information to be received.

Secrecy. Although secrecy is important in the development of most new military capabilities, the novelty of satellite reconnaissance and its possibilities for peacetime application are believed to dictate special secrecy considerations.

An operational Feed Back capability appears to offer the distinct possibility of reversing the present U.S. position of inferiority in strategic reconnaissance as compared with the Soviet position. This possibility is more evident when viewed in the light of the expected lethal radii of the bombardment weapons which would be contemporary with Feed Back operation.

Counteraction against Feed Back could be effected in many ways, including action against the vehicle, action both physical and political against the communications stations, and attempts at deception. These will be discussed in more detail below. In any case, the key to avoiding countermeasures here seems to lie as much in disguising the U.S. intent to develop and use Feed Back as in preventive design or operation.

It is obviously impossible to hide the probability of a satellite project. However, if the reality of a Feed Back development effort is concealed for a sufficient time, development of countermeasures by the Russians may be effectively retarded.

Thus, if and when a satellite actually enters development, that status should be kept as secret as possible. In the event that this security were breached, the purpose of the project could still remain under wraps. Failing this, the operational aspects should be highly classified—particularly launching time, place, and orbit parameters.

Political and Psychological Factors

The anticipated direct military value of Feed Back reconnaissance was discussed under "Value of Feed Back Reconnaissance," page 78. Here, we consider the political and psychological implications of the satellite reconnaissance vehicle.

Political Problems. The nation which gains by a shift in the balance of military capabilities generally acquires greater freedom in policy planning and

determination. In the present instance, however, it is difficult to forecast the actual policy effects of a successful satellite, because it is impossible to predict how the governments involved may react to the resulting strategic shift. For example, use of the satellite would not affect Soviet policy decisions at all unless the Soviet leaders knew about it. If secrecy about the entire operation were decided upon and maintained, there would be a policy effect only in the United States. On the other hand, if secrecy were either not desired or were breached, Soviet policy also would be affected.

Can the magnitude and the nature of such policy effects be foreseen? Can we predict whether Soviet policy changes will be desirable or undesirable from our point of view? The military value of a successful satellite is assumed. But its employment may have undesirable political consequences. Must we sacrifice the military advantage to avoid the political risk? It is not merely a question of preparing suitable policies to counteract undesirable political effects as much as possible, and, conversely, to exploit advantageous situations to the fullest. It is obviously important to get as good answers as possible to such questions and to examine the whole range of policy effects that might result from use of the satellite.

If a shift in the balance of strategic capabilities is great enough, the power against which the shift goes may be either discouraged and induced to make concessions or, on the contrary, frightened into initiating war at the earliest possible moment. United States possession of adequate strategic intelligence data, particularly for targeting purposes, would increase the risks the Soviet Union would have to face in war, and might therefore be expected to strengthen any deterrent influence that U.S. preparedness might exert upon Soviet policy. But we must not exaggerate the deterrent effect of the satellite. It does not seem likely, for example, that the Soviet government would go so far as to cancel a planned all-out attack on the West merely because it learned that the United States had available information concerning SUSAC installations. Such a plan almost certainly would call for anti-SAC strikes at the first blow, and it probably would not be put into effect unless Soviet leaders were convinced that SAC could be neutralized sufficiently to prevent effective retaliation against *any* target in the Soviet Union. It is not the addition of SUSAC bases to the list of possible retaliation targets that would "deter" the Soviet Union, but the first-blow-proof retaliatory strength of the United States. If the Soviets estimated that the United States could withstand an initial strike, improved U.S. strategic intelligence would enhance the existing deterrent effect. But our greater intelligence capability alone would not provide deterrence.

On the other hand, intelligence on SUSAC bases would increase greatly the risks faced by the Soviet Union should the United States initiate war. Attacks upon SUSAC bases could be included in the U.S. plan for a first strike, thus threatening to deprive the Soviet Union of a retaliatory capability. This, in turn, would make waiting more risky for the Soviet Union and would enhance the urgency of forestalling a possible preventive blow by the United States. In other words, our satellite operation could have an extremely undesirable provocatory effect if the Soviet Union interpreted it as a prelude to imminent attack. Hence, when the device is put into use, it will be important to dispel any impression that a U.S. attack is imminent. Secrecy, if feasible, will be most useful in this context. If not feasible, other measures should be sought to dispel any such impressions.

We conclude that, apart from possible panic following discovery, a satellite operation would not be likely to produce an appreciable "grand policy" effect—deterrence of provocation—upon the Soviet Union. Depending on circumstances, discovery of the new intelligence capability of the United States might reinforce existing Soviet propensities to be either deterred or provoked.

How would acquisition of a novel reconnaissance capability affect U.S. strategic policy? Would it lead to reorientation of that policy? Strategic bombing plans could be revised, because planning strikes against Soviet strategic air targets would be a practical possibility. Strategic counter-air strikes promise a high payoff if delivered ahead of a Soviet strategic bombing attack. But because factors other than reconnaissance capabilities are likely to determine a choice of strategy, we cannot foresee the line of U.S. grand policy at the time when the satellite begins to pay off. It would seem likely that possession of the new technique would afford a wider choice of strategies, including the one based primarily on counter-air strikes. Such a strategy might be preferable to attacks on city or industry target systems for political as well as for strategic reasons.

In addition to the grand-policy effects of the satellite operation which we have considered, there are likely to be policy effects of lesser scope. If the Soviet government learns about the operation, it will, presumably, attempt legal or political countermeasures short of war to deprive us of the equalizing intelligence we seek. Such countermeasures may involve local violence short of war.

Use of the satellite might bring a charge of violation of Soviet sovereignty. Probably the Soviets would do everything in their power to make the charge stick and to exploit it to their political advantage by making the United States appear as a violator of international law. Other specific countermeasures might

consist in litigation, propaganda campaigns, political pressure on other governments taking part in the operation, and, circumstances permitting, violent attack upon servicing stations.

The success of such a countercampaign would depend on the extent to which the target audiences—including the U.S. government and public—would feel compelled to admit the moral justification of the Soviet charge. It is not impossible that people on our side would be impressed by the strength of the Soviet moral position. Western policy-makers and the public have long felt that it is incumbent on every power to comply with the legal traditions concerning mutual respect for each other's territorial sovereignty. The idea of jeopardizing this body of tradition, and of being saddled with the responsibility for nullifying it, creates serious political problems. The Western powers, including the United States, might well put a higher value upon avoiding such political risks than upon equalizing military reconnaissance capabilities. The satellite operation seems to be politically vulnerable in this sense. The State Department is likely to be conscious of these difficulties, which must be taken into account.

This political vulnerability could be reduced by working out in advance a legal position which would anticipate the Soviet charges and attempt to meet them with effective counterarguments. The United States might well challenge the legal justification of the Soviet Union's practice of inhibiting the flow of information. The United States could argue that the abnormal, totalitarian suppression of normal information concerning the Soviet Union compels the world to restore equality of access to data, by unconventional means if necessary. If the operation cannot be kept secret, it is likely that the Soviets will provoke a public discussion to exploit their "superior" legal and moral position. And they may well succeed unless we are adequately prepared in advance—legally, politically, and morally.

If communications stations were located in relatively weak countries close to the USSR, the Soviets could bring the strongest political pressure—possibly even violent pressure—to bear in an attempt to interfere with the ground-servicing operation. Therefore, if feasible, we should use delayed transmission of intelligence data to stations in territory under U.S. jurisdiction.

Secrecy and Disclosure. Many of the problems and difficulties we have discussed would not arise, of course, if the operation could be kept secret from beginning to end. A secret operation cannot produce any policy effect upon those not informed about it. It follows that secrecy would be highly desirable until the satellite was in operation. Whether the satellite should remain secret

after it is launched will depend on circumstances. For example, if launched in wartime, we should undoubtedly want to keep it secret. In peacetime, it would be desirable to make its existence known under circumstances in which such knowledge would deter the Soviet leaders.

But it is questionable whether secrecy could be maintained. Once the satellite was in its orbit, the Soviet government could discover it by chance, even though measures were taken to make detection difficult. Even before the actual launching, the Soviets could learn of the project through security leaks or espionage—not a negligible consideration, given the magnitude of the operation and the fact that friendly governments might possess information. Thus, we cannot proceed on the firm assumption that knowledge of the operation can be withheld from the Soviet government. The most we can do is to attempt to maintain secrecy as long as is desirable or possible, while providing for alternative policies in the event that secrecy is breached.

In view of the many popular articles already in circulation about the satellite, secrecy cannot be absolute in any case. Nor does it seem to be realistic or desirable to inhibit similar publications in the future. What should be avoided is advance publication of U.S. policy decisions to use the device and also any indication of our purposes. Public discussion of the uses and of the pros and cons of the project would be harmful, because it would enable the Soviets to indulge in political warfare of the kind indicated above.

The danger of provocation and of successful Soviet political warfare would seem to be most acute if the Soviet government were to learn about the satellite before it was launched. If the satellite were not discovered until after it had begun to pay off, the provocatory effect and the chances of successful political countermeasures would be very considerably reduced. The critical period would be that just preceding and immediately following the launching, and it would be particularly important to avoid leaks and disclosures during that period.

If the Soviet Union had a one- or two-year period in which to build up a major propaganda campaign against the satellite, this might include action in the United Nations, the preparation of a case before the International Court of Justice, and political and military threats regarding possible Soviet acts if the United States went ahead with the satellite. Political problems might become so serious that it would be difficult or impractical for this country to go through with the program. Before the critical period, a normal amount of unofficial publicity concerning the technical problems raised by an artificial satellite would do less harm than would an abrupt blackout of all publicity. After the critical period, with the increasing likelihood of chance discovery, it would be

time to plan disclosure and moral and political justification of the accomplished fact.

Since Soviet technicians are probably aware of the reconnaissance capabilities of a satellite, it does not appear likely that the Soviet government can be misled as to the purpose of operation by cover stories alleging a different use.

Popular opinion, both friendly and hostile, is likely to associate the satellite with a superweapon of destruction. Hence, both deliberate and unintended disclosures may produce unfavorable psychological effects. The public may become excited and apprehensive. Even if reassured, it may continue to expect further, more destructive, developments. While the technological achievement represented by the satellite could enhance U.S. prestige, it would also be likely to enforce adverse stereotypes such as the idea that U.S. technicians were interested mainly in developing more and more frightful and universal engines of destruction.

It is impossible to plan a complete disclosure policy covering the period up to, including, and immediately following the launching of the satellite. What can and must be disclosed, and in what form, can best be determined in the light of developing circumstances. But it is possible to formulate a few general principles. Most important, until successful completion of the reconnaissance mission, the entire project should be handled as a sensitive subject. Avoidance of a strong provocatory effect and the need for an effective moral and political line to counteract any propaganda offensive the Soviets may launch should also be kept in mind.

Conclusions. The following specific policy recommendations can be formulated on the basis of the above discussion:

1. The earliest possible completion and use of an efficient satellite reconnaissance vehicle is of vital strategic interest to the United States.
2. The satellite operation must be considered and planned on a high policy level.
3. The project should be handled as sensitive matter as regards disclosure. Secrecy concerning the operation should be maintained, particularly during the period just preceding and immediately following launching.
4. The extent and nature of disclosures regarding the actual operation should be determined in the light of the general political situation.
5. The international legal and political implications of the operation should be carefully considered; defense against possible legal attacks from the Soviet side should be prepared.

6. Delayed transmission techniques, permitting receiving stations in territory under U.S. jurisdiction, are preferable to instantaneous transmission, because they would reduce the political vulnerabiltiy of the project.

Physical Vulnerability

The vulnerability of the satellite vehicle itself will depend to a great extent on knowledge of its location or, indeed, of its existence.

The Soviet Union could acquire knowledge of the satellite's location in several ways. First, the information might come from operatives in the United States or at the vehicle firing site, wherever it might be located. Second, a determined search for the vehicle might be made if the Russians knew of its existence and nothing more. This might result after disclosures in our press. Should they discover its existence, they might be able to set up Schmidt-type tracking cameras to search all over the sky and eventually record on film the vehicle's location and path.

Third, the vehicle might be sighted by chance. The possibility of this occurring would be reduced by use of the 83° retrograde orbit. The vehicle could be seen by the naked eye only when the observer was in darkness and the vehicle in the sunlight. With the 83° orbit, this could be done only around the Arctic Circle, where the population density is low. On the other hand, a number of observations per day might be made by one observer. Such a sighting would ease the astronomical search problem to some extent.

Fourth, the Soviets might intercept a transmission from the vehicle. However, these transmissions would be highly directional, and only electronic stations near the communications stations would be able to receive the signals. Even then, it is difficult to see how they could interpret such a chance signal if picked up, particularly if they were not aware of the satellite's existence.

Sighting by Russian radar is not likely, because the satellite's radar cross section is only about a square yard in size and the vehicle will be 300 mi away, at least.

Thus it is possible that the Soviets might discover the satellite vehicle. If they could determine its orbit characteristics accurately, a vehicle could probably be developed to intercept and damage the satellite (see below). The need for extremely stringent security measures may thus be inferred.

Only cursory inspection has been made of the satellite's vulnerability to ground interception.

It has been assumed that the vehicle's location would be known to the enemy. It was also assumed that an interception path would approximate that of a sounding rocket.

A two-stage sounding rocket has been fired in this country to a 250-mi altitude (Wac-Corporal). It is probable that the Russians now have similar missiles.

What means are there, then, for interception of the satellite? At a 300-mi altitude the atmospheric density is so low that blast effects will probably not be appreciable. However, the use of flak-type warheads is still possible. These might throw a large number of small fragments into the path of the vehicle. An atomic warhead is also a possibility.

The missile system that might be employed for the barrage rocket would have command guidance and fusing. The rocket would be guided to the satellite altitude at the peak of its trajectory. The explosion of the warhead at this altitude would result in a spreading fragment pattern, the center following the missile trajectory. The satellite would presumably move through this pattern with a reasonable probability of damage.

An extremely cursory inspection of the flak rocket showed the possibility of disabling the Feed Back vehicle with fragment warheads of several hundred pounds, if the vehicle location were known exactly and if control of the interception missile could be accurate to 0.1 mi at altitude.

An atomic warhead might be used to disable the satellite vehicle. It is probable that, by the time a satellite is operational, a 1-MT-yield weapon will be available in a size small enough for use in a high-altitude rocket. A very-high-altitude burst, in a region of no appreciable atmosphere, would produce thermal radiation but no blast. An atomic weapon of this yield would result in a 2000°F temperature rise in a 0.020-in. steel skin at a distance of 4 mi, or the same temperature rise in a 0.1-in. steel skin at a distance of 2 mi. Such temperatures, of course, would result in disablement of the auxiliary powerplant and probably of a number of other satellite components. Effects of the bomb's neutron emission on a Feed Back powerplant would appear to be small compared with the effects of thermal radiation on the skin.

The likelihood of the successful disabling of the vehicle by the Soviets can be discussed only in a qualitative way. Time would certainly be of the essence, for if the Soviets did not acquire knowledge of the vehicle until after several months of operation, the advantage that they could gain by knocking it down would be negligible. On the other hand, if they could disable each successive satellite within a few hours of launching, they could effectively prevent our obtaining reconnaissance.

How far the Soviets will go to prevent our gaining data on their strategic targets is impossible to predict. It is possible that an interception development would be as expensive as the Feed Back program.

The Soviets might take direct action against the ground stations on foreign soil. Electronic countermeasures might include interception of the television transmission and jamming of our communications system.

Interception of the vehicle transmission would still not be effected unless the Soviets duplicated our command system. Further, Feed Back commands could include a time interval before turn-on that would prevent Soviet intrusion, if two communications stations in the ZI were employed.

About the same considerations as those applying to the vehicle-to-ground transmission link would apply to the problems of security against jamming or seizure of control of the vehicle by a transmitter based in the Soviet territory. The directional antenna of the vehicle could be expected to provide a protection factor of approximately 1000 when the command receiver was used in the manner discussed under "Command Link," page 117, and the use of a relatively narrow band of frequency, placed with some precision with respect to the vehicle transmitter frequency, would provide an additional protection factor of 10 or 100 against barrage jamming. Jamming the space-to-ground transmission would therefore require from 100,000 to 1,000,000 watts of continuous-wave power, even when used with an antenna of the same size as the Feed Back ground station receiving antenna.

In summary, several fairly clear-cut facts emerge. First, if the Soviets did not acquire knowledge of the vehicle's existence, then of course it would be relatively invulnerable. Second, if they acquired this knowledge too late—i.e., too late to prevent us from getting a start in the reconnaissance gathering operation, or too late for them to develop countermeasures—then there would be no cause for concern. However, if they did know of the intent and progress of the Feed Back project in time to develop a weapon, and if they could establish the satellite's location by means of intelligence or tracking, they might attempt to disable it. Third, while jamming of the ground-station antenna is possible, doing so on a continuous basis would probably involve a prohibitive cost.

Facilities Requirements

Because we need relatively invulnerable sites for communications stations, these have been assumed to be on U.S. territory, perhaps within the ZI.

Ground-based facilities required for the Feed Back reconnaissance system

would not differ materially from missile-launching, radar, and intelligence-processing facilities already in existence. In general, the launching base would resemble currently planned ballistic test missile facilities at the Air Force Missile Test Center, Patrick Air Force Base, Florida, except that requirements for ground guidance and instrumentation would be substantially reduced. A communications station would have a strong resemblance to a small radar installation and could, in fact, be combined with or made to resemble such a station. The intelligence center would require office-type facilities such as are provided for similar organizations under the Directorate of Intelligence, HqUSAF.

Launching Facilities. Operational facilities at the launching base are estimated to be as follows:

Assembly building, hangar type	16,000 ft^2
Launching pad, concrete	10,000 ft^2
Blockhouse, underground	2,500 ft^2
Road, 50-ft wide, Class A	1 mi
Road, 25-ft wide, Class B	500 ft
Railway spur line to base and to launching pad	5 mi
Cable trench, underground	500 ft

In addition, support facilities would be required for a total base complement of about 450 officers and airmen.

Communications Facilities. Operational facilities at the communications site are estimated to be as follows:

Operations building	
Programming and planning	900 ft^2
Display, recording, printing	800 ft^2
Computing	300 ft^2
Storage vault	200 ft^2
Test equipment and spares	300 ft^2
TOTAL	2500 ft^2
Antenna building with radome	500 ft^2
Communications building	1000 ft^2

In addition, support facilities would be required for a total complement of about 250 officers and airmen.

Intelligence Processing Facilities. The office space required for the intelligence center is estimated to be as follows:

Selection and integration	3,000 ft^2
Interpretation and analysis	15,000 ft^2
Communications	1,000 ft^2
Files	5,000 ft^2
Reproduction	2,000 ft^2

These facilities would be used by approximately 250 people. If located in Washington, D.C., for example, the personnel would not require additional support facilities.

Development, Testing, and Manufacturing Facilities. In the Feed Back program it is difficult to distinguish between "development" and "production" and equally difficult to separate development and manufacturing facilities. The first complete prototype vehicle, for example, may prove to be the first operational (orbiting) satellite. For the limited production contemplated, this program will resemble the first few years of several missile programs (such as those of Snark or Navaho) which include the fabrication and launching of test vehicles. Manufacturing and assembly facilities for Feed Back vehicles, then, should resemble the facilities required for experimental missile programs, except that more finished engineering and tools will be needed. Naturally, it is expected that the experience gained in the planning and implementing of other programs will be of value in the Feed Back project.

In general, facilities will be required for the following missile components:

Airframe	Optical
Rocket propulsion	Television
Nuclear powerplant	Electromechanical
Environmental test	

Facilities of these types are already in existence at various contractor and USAF installations. Reliability testing of airborne and space-borne equipment would involve some special facilities; e.g., environmental testing of a complete prototype satellite stage would require an evacuated sphere about 30 ft in diameter having temperature control, instrumentation, and means for simulating the air-to-ground communications. The receiver vessel for a blow-down type of wind tunnel might be adapted for this purpose.

The field-test program would require a test base comparable to AFMTC, Florida, including an assembly hangar, a launching station, central and down-range instrumentation, facilities for data reduction, and other field-test engineering functions. Test launchings would probably utilize progressively more complete vehicles, culminating in long-range surface-to-surface flights carrying prototype reconnaissance equipment.

Development, Scheduling, and Cost Estimates

In considering the time and cost estimates that are given in the following pages, it must be understood that all the numbers are rough estimates. They are

an indication of the time and cost that can be achieved if all goes well, based on past missile and aircraft experience, the present state of the missile art, and satellite developments necessary beyond the present state of the art. Of course, any amount of delay or expense can be introduced by events that are unforeseeable, and the reader may choose to apply his own safety factors to our estimates.

Elapsed times are based on rates of effort similar to those of some existing large missile programs. A crash program or "Manhattan District" type of effort has not been assumed. We should be naïve, however, to believe that no program delays will occur: we can only hope that they will not be major ones.

Estimates of the costs involved in the operation of the intelligence center are more indeterminate than other estimates, since this part of the system is most difficult to describe many years in advance. On the whole, RAND's Cost Section is confident that the real costs will not exceed the estimates as given by more than a factor of two. That is, where a cost of about $165 million is discussed on page 165 (an approximate sum of the figures that are broken down in the next few pages), it is considered to be very unlikely that the final real cost will exceed $300 million.

Tentative Program. As the Feed Back program is projected farther into the future, it naturally becomes more difficult to anticipate and predict development problems and their solutions. Because a schedule must be set up to give some realism to the programming and costing of the research and development effort, an attempt is made here to outline in gross form the highlights of a program which will be fairly realistic.

Major areas of research and development effort can be classified as follows:

1. The study, design, and development of vehicle and ground-based components; i.e., airframe and propulsion, nuclear powerplant and attendant equipment, guidance and control equipment, airborne communications and intelligence equipment, and ground equipment.
2. The environmental and reliability testing of successively complete final-stage vehicles and payloads, first on the ground and then in flight, utilizing concurrently developed ground equipment.
3. The planning of studies and basic systems research: a concurrent and continuing effort which includes the development of alternative payloads and applications.

A number of major test sequences are contemplated:

1. Component testing will be involved in roughly the first 3 years of the program (starting in fiscal 1955). (Time: 0 to 3 years.)
2. Experimental units of the major parts of the payload will be assembled and tested. (Time: 2½ to 4 years.)
3. Experimental packaged units will be assembled and given continuously monitored reliability and duration tests under conditions as close to the environmental conditions of the actual vehicle as can be predicted and achieved. (Time: 3½ to 5½ years. At the end of 5½ years it should be possible to begin turning out modified packaged units.)
4. Flight tests should start some 4 years after the initiation of the program and continue for 1½ years. During this time successively more complete vehicles will be tested and flown, components will be tested in flights, and the data obtained will be fed back into the packaged, modified final payload design. (Time: 4 to 5½ years.)
5. At the beginning of the sixth year, a completely operational system test can be performed with the modified payload. It should be possible to put one or two vehicles in the orbit at this time, if so desired, and all ground-based equipment should then be prepared to accept data from a successfully orbiting vehicle.

We estimate that the first six operational vehicles will use some components from the development program while a switch-over is made to a production program for ~~fifty~~ 12 operational vehicles. This number of vehicles allows some leeway for vehicle unreliability and possible alternative payloads other than reconnaissance.

The production schedule for operational components and vehicles is assumed to be as follows:

Airframe and propulsion	Begins 5 years after initiation of contract
Guidance and control equipment	Begins 5½ years after initiation of contract
Television powerplant	Begins 5½ years after initiation of contract

The first operational vehicle will be assembled on the launching site 6¼ years after the contract initiation, using some development components (as will the successive five vehicles).

Complete vehicles would be manufactured and assembled as follows:

6 vehicles	Assembled at the rate of one per month, beginning 6¼ years after contract initiation.
44 vehicles	Assembled at the rate of two per month, beginning 6¾ years after contract initiation, using components produced solely under the production program.

Summaries of the time and cost estimates for the Feed Back development program are given in the figures which follow.

Figure 59 gives a breakdown of the engineering development effort by task, and the estimated development program.

Figure 60 gives a schedule of the major task completions.

Figure 61 gives an estimate of the minimum flight-test requirements for the final phase of the development program.

Development of Vehicle Components. Some of the problems anticipated in the development of vehicle components are discussed below. It should be pointed out that proper phasing in the development of both vehicle and ground components is important for the achievement of the best performance of the system. Obviously, if design freezing dates are chosen too late, the equipment will not be ready in time; on the other hand, if they are chosen too early it will not be possible to take full advantage of the high rate of state-of-the-art development, especially in the field of electronics.

1. *Airframe and Propulsion.* The development of the airframe and rocket motors should offer few problems, because of similarity to present-day missile hardware. In fact, the development of gasoline-oxygen motors and of gimbaling methods is assumed in this study to be covered by other programs.

2. *Nuclear Powerplant.* No insurmountable difficulties are foreseen in the development of the powerplant described. However, because of the novel nature of the heat source and its application, considerable study, experimentation, and testing will be required. Specifically, this will involve determination of the heat-source characteristics, design data for the power unit and heat exchangers, and a further study of operation of the powerplant in a vacuum and with no natural gravity. Prolonged operation of a sealed system in a radiation field should be investigated to determine the effects of corrosion and dissociation. A self-regulating control system will require development to permit constant power output under the ambient extremes of sun and shade. The engine generator will have to demonstrate reliable operation for a period of 1 year and also its ability to withstand launching and ascent conditions while in operation.

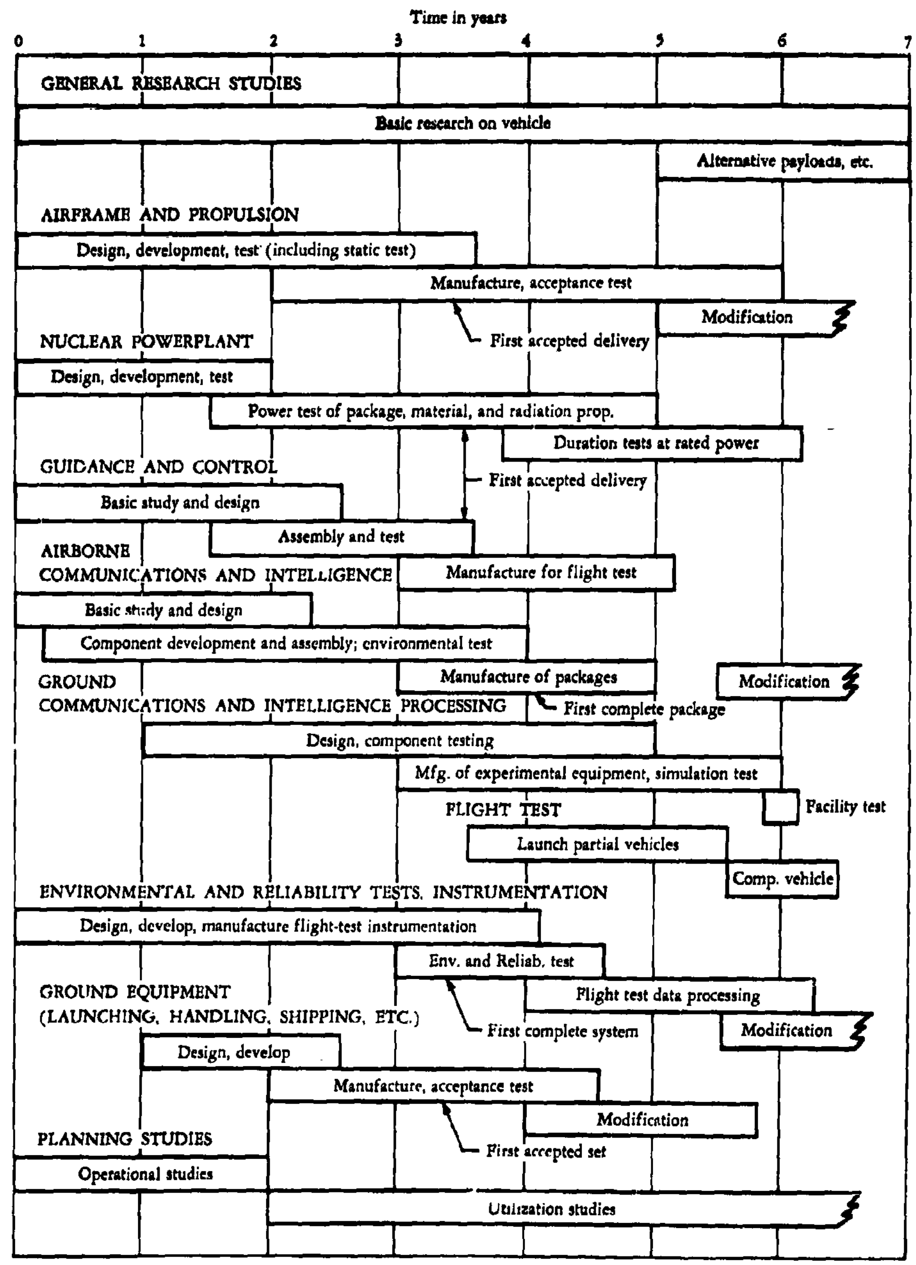


Fig. 59—Tentative research and development program for Feed Back

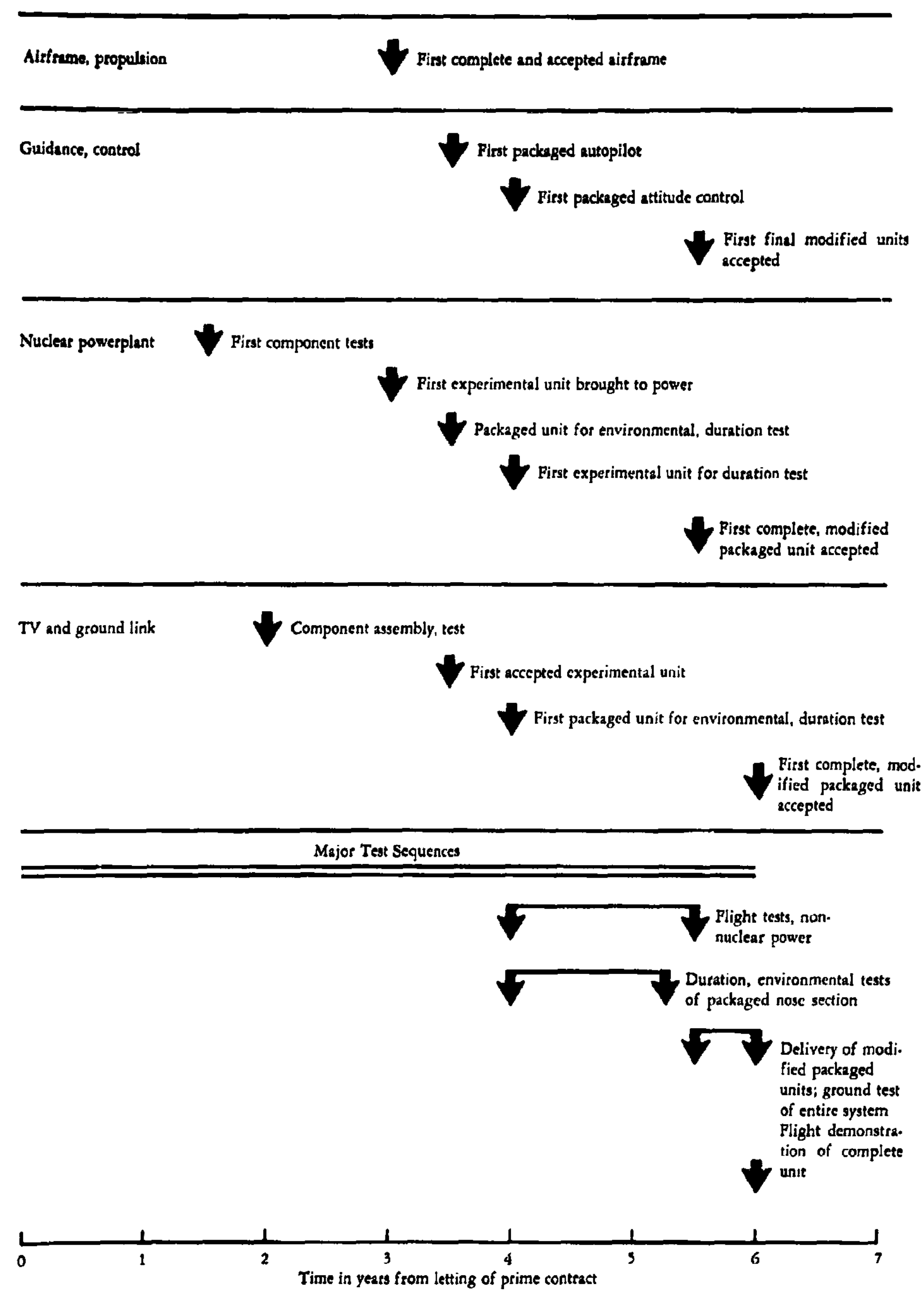


Fig. 60—Possible delivery sequence of major system components

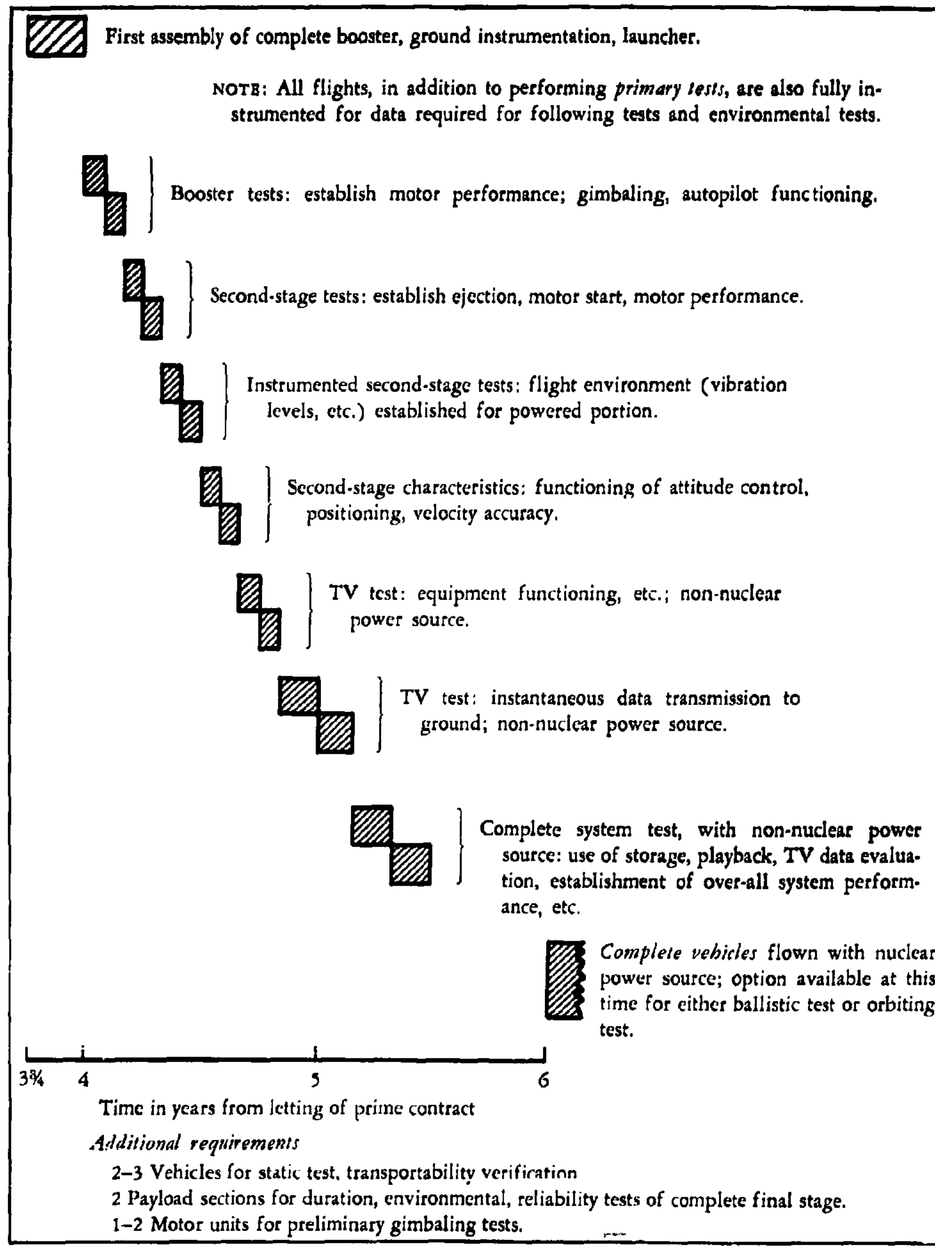


Fig. 61—Minimum preliminary and flight-test requirements

3. *Guidance and Control Equipment.* Preliminary studies indicate that the present state of the art in guidance and control components is more than adequate for Feed Back requirements; therefore, the development required will be mainly for the purpose of designing and integrating components into this specific system.

4. *Airborne Communications and Intelligence Equipment.* It is expected that the airborne data-storage equipment will require the most development in this category for about 3½ years after design studies are completed. Fortunately, there is a commercial interest in the storage of television pictures on the part of broadcasters, and work is under way on storage devices of this type. Development in this field will probably substantially reduce the amount of magnetic tape required to store a given amount of data. For satellite use, considerable weight and size reduction of the tape recorder will be needed.

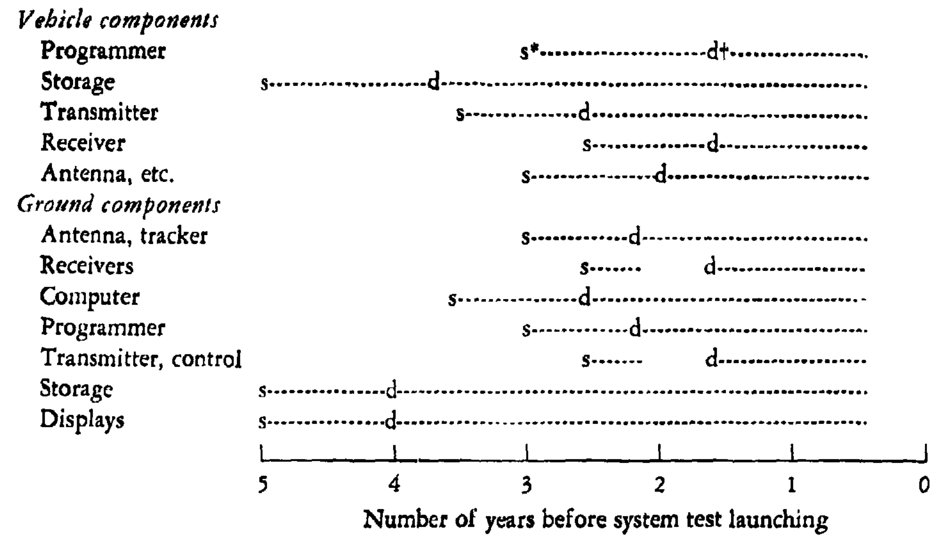
The airborne transmitter will require about 2 years of final development, mainly because of the need for extensive life testing of various tubes and other components.

Final development of the command receiver will require about 1 year after completion of design studies and the complete specification of characteristics. No particularly difficult problems are anticipated. Much experience may be drawn from receivers designed for other missile applications. It is anticipated that reliable, rugged transistors will be available for use in many of the circuits of the receiver by the time final development is undertaken.

The vehicle antenna, control, and diplexer will require about 1 year of design studies and 18 months of final development. No serious development problems are anticipated, since a large amount of information has been accumulated from the intensive development of radar systems, waveguide components, and other X-band devices. The degree of positioning accuracy expected of the antenna control will require no special development.

A proposed schedule giving the phasing of all airborne and ground-based communications equipment is given in Fig. 62.

In general, as long as the Image Orthicon is used, the television system represents a problem in engineering development rather than one of fundamental investigation into unknowns in the field of physical sciences. However, the Vidicon, as an example, is much simpler and takes less power than the Image Orthicon. It has comparable resolution, but requires much higher light levels; thus, unless its sensitivity can be markedly improved, it will take prohibitively large optics. A fundamental research program on Vidicon sensitivity is presently



*Study.
†Development.

Fig. 62—Proposed development schedule for Feed Back communications equipment

under way at RCA, but there is no way of forecasting a successful outcome.

Probably the construction of reliable, low power drain, focusing, and control circuits for the Image Orthicon camera tubes will represent one of the most difficult problems for the future Feed Back program. This circuitry, apparently, is a straightforward engineering development problem.

Development of Ground-based Components. The development requirements for ground-based components are reviewed here. Less emphasis on reliability is needed for these components, since they are readily accessible at all times for checking and replacement. However, from the standpoint of operation of the over-all system, it is desirable to impart to the ground components as high a reliability as is commensurate with good design and reasonable cost.

1. *Ground Communications Equipment.* Approximately 1 year of design study and 18 months of final development will be required for the ground antenna, control, and diplexer. Some features of the design of the ground-antenna mounts can be taken from the modified radar sets which are currently in use at missile test ranges. The mount will be large, if a 20-ft-diameter reflector is found to be desirable, and may be required to track smoothly through the

zenith; however, no great difficulty is expected in developing the required positioning accuracy. The diplexer can be quite similar to that designed for the vehicle. No development will be required for the radome to house the antenna and associated equipment. Design and development of track-scanning and error-detection equipment can proceed in parallel with antenna development.

Ground receivers should require about 1 year of development after a 6-months' design study. There is a considerable amount of design experience with receivers in the frequency band which will probably be used.

An orbit computer and predictor and associated storage units will require about 2 years for complete development after a 1-year design study to establish all the computer functions.

The programming equipment will require approximately 1 year of study followed by 18 months of development. Since the programmer is the means of putting operating decisions into the system, considerable human engineering will go into the development of adequate display and planning aids and methods of formulating and checking instructions for the vehicle.

Development of the frequency control and command transmitter should be fairly straightforward, requiring about 1 year after a 6-months' study. While there may be some complication in the frequency control circuitry, no unexplored techniques will be required.

Considerable development will be required for the data-storage and display equipment on the ground, although the ground equipment can be simpler than the corresponding vehicle equipment because space and weight are not at a premium and the storage and playback functions can be separated. Development of the ground storage equipment can therefore be carried out in somewhat less time than that required for the airborne package.

The proposed scheduling and phasing of airborne and ground communications equipment is given in Fig. 62.

2. *Intelligence Processing Equipment.* Since the Feed Back reconnaissance system will produce information at a very high rate, there will be a need not only for development of display and storage mechanisms adequate to handle information at this rate, but also for selective devices to pick out those portions of the data which are important from the standpoint of the desired intelligence. Design studies in this field of selecting and processing intelligence should be started as soon as possible.

A useful selective device is the proposed mosaic printer, which will reverse the vehicle scanning process to translate tape-stored data into images on photo-

graphic film. The end product of the mosaic printer, although not a perfectly matched mosaic, will present the individual pictures in their correct relationship to facilitate selection and further study. Although complex, the mosaic printer is not expected to cause great development difficulty, since it will combine proved mechanisms with those in development for the vehicle.

Display equipment for selectors and interpreters will require development of image retention methods, of which several have been proposed, and of ways to vary the rate of frame presentation and mark frames for future action. These do not appear to be difficult problems once the basic display unit is developed.

An important part of future Feed Back development effort should include improvement and more critical analysis of the television simulation model and also operational research into the role of Feed Back in the total intelligence picture.

3. *Ground-handling and Launching Equipment*. The ground-handling equipment (such as the assembly dollies, transporter, and launching platform) will offer no special development problems, being similar to equipment presently existing or planned for guided missiles. Test equipment, however, may require more development, although this will conceivably be a natural process concurrent with the development of the item to be tested. Several mitigating factors may be mentioned with regard to test equipment: first, the test equipment will not have to be designed for rugged use or even for average Air Force skill levels; second, it will not have to achieve a prolonged state of readiness or a high launching rate such as is required of missile test equipment; third, it will be custom-made and not produced in quantity.

Estimated Costs. The cost estimates presented here are to a certain extent based on experience gained from the study of present-day weapons systems—particularly guided missiles. It is not expected, as a result of uncertainties in the prediction of future development trends, that the over-all systems cost of the satellite will become more than double the amount stated.

1. *Over-all Program Costs.* Estimated costs for developing, building, and operating a complete satellite reconnaissance system are summarized here and are broken down in subsequent sections. The basic assumptions used in obtaining these costs are as follows: (1) a development program as previously outlined, including fabrication of test components; (2) costs of development and manufacturing facilities which have not been included (except environmental test); and (3) a total of 12 operational-type vehicles.

The total development cost is estimated at $118 million, and the total cost of operational vehicles and facilities is estimated at $31 million. The annual operating cost of the complete system is estimated at $14 million. A further breakdown of operational system costs is given below.

Facility	Cost in Millions of Dollars Investment	Annual Operating
1 Communications station	3.7	3.0
1 Launching base with ~~50~~ missiles plus spares	26.4	9.4
1 Intelligence center	.8	1.7
TOTAL	30.9	14.1

2. *Development Costs.* An estimate of engineering and experimental-shop manpower for the Feed Back development program is shown in Fig. 63. Engineering effort is broken down into the various categories listed on the figure. A total of 78,000 man-months is estimated for the 6½-year development period, which is assumed to begin with contract initiation and to end with the launching of the first operational-type vehicle.

The rate of expenditure and cumulative cost of the development program are indicated in Fig. 64. This cost is assumed to include all engineering and shop time, overhead, and material required for building test components (see Figs. 59 through 61). Also included is the cost of experimental testing. The following facilities are not included in the development cost:

Propulsion test — Static test
Launching test — Reliability test
Operational facilities

Total development cost of $118 million will entail a maximum rate of expenditure of $30 million during the fourth year. Because the entire program, and consequently the cost, is susceptible to considerable variation in detail, the costs quoted above are to be considered as being only representative and applicable in particular to the time schedule previously outlined.

It may be possible to attain the end goal of the program from 1 to 2 years earlier at a considerable increase in cost. Such increases will come about primarily as a result of duplication of manpower, facilities and equipment, and greater raw-material purchases plus procurement of purchased parts at a higher rate (to provide for duplication and contingencies). Double-shift activities may

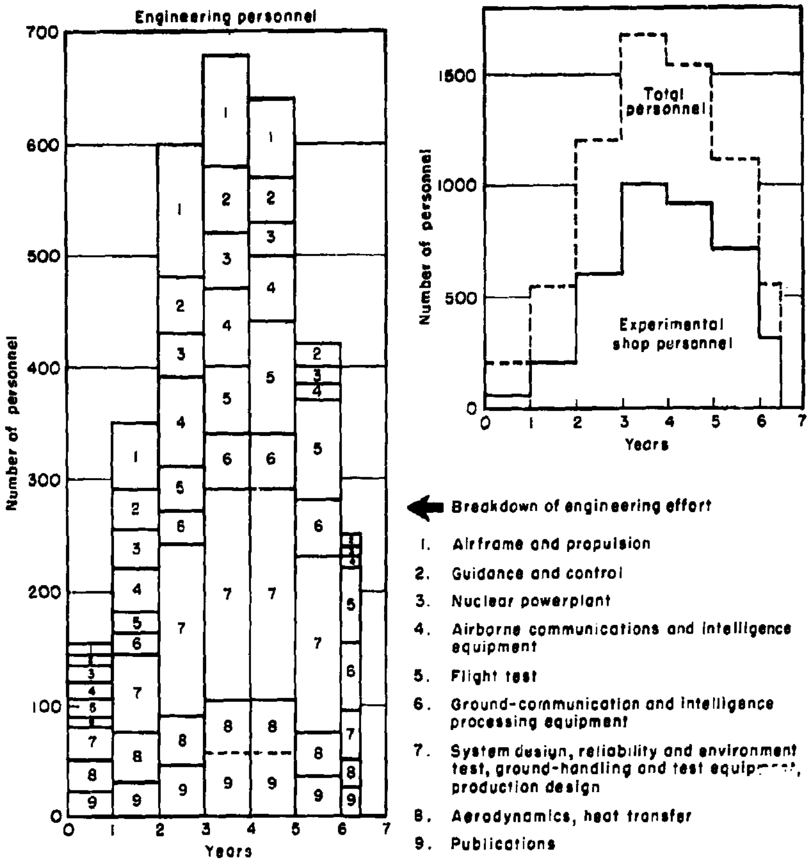


Fig. 63—Estimated personnel for Feed Back development program

result for both the prime contractors and for subcontractors. In addition, other programs may contribute relatively fewer state-of-the-art benefits as this one is accelerated, so that a proportionately greater development effort will be required on components.

3. *Vehicle Costs.* Two estimates are made of vehicle costs, for production runs of 50 and 12 articles. In both cases the communication and intelligence components are estimated as though they are single production units, not only because of expected component variations, but also to allow for improvement in reliability. In general, development costs are excluded, except where development effort seems necessary to fit components into the over-all system. Variations in the payload are assumed to have negligible effect on vehicle costs.

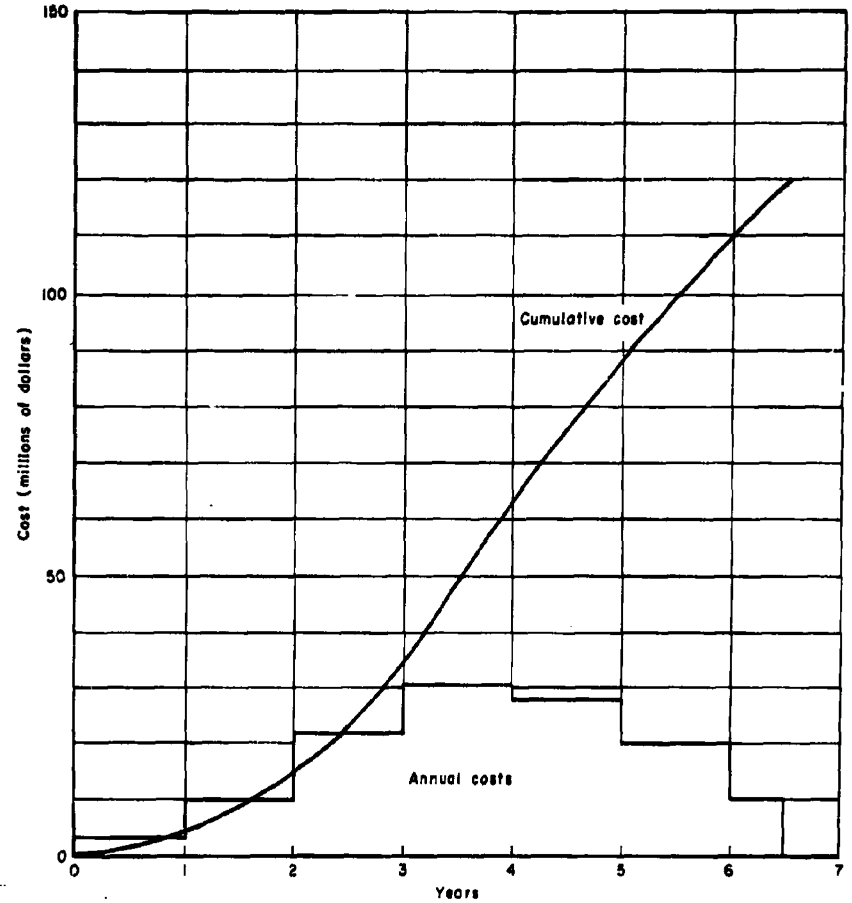


Fig. 64—Annual and cumulative cost estimate for Feed Back development program

The cost per vehicle is broken down as follows:

Component	Total Production in Thousands	
	50 Vehicles	*12 Vehicles*
Communication and intelligence equipment...	167	167
Airframe	420	514
Propulsion system	110	166
Reactor and power-supply controls	250	250
Attitude and orbital controls	50	76
Intercomponent controls	25	37
Fuel	8	8
TOTAL	1030	1218

4. *Operational System Costs.* The estimates of communications-station and launching-base costs are probably conservative because these are assumed to be independent facilities located in Alaska. The cost of building and operating installations in the United States will be substantially less, particularly if existing facilities are used. For example, a launching base using an existing test center in the United States can be constructed for about 25 per cent less than the Alaskan base and operated for about one-third its annual cost. The intelligence-center estimate is not as conservative, being based on a location in Washington, D.C., using existing office space, and providing a living allowance for the personnel.

Cost breakdowns for the three major operational facilities are given in Tables 2, 3, and 4.

Manpower estimates for the complete operational systems are given in Table 5. Only technical personnel are included; support personnel are not given in detail, although they are included in the system costs. No allowance is made for civilian technical representatives or for operation on more than one shift, except that the communications station is allowed two shifts for costing purposes.

Table 2

INTELLIGENCE CENTER

	Costs in Thousands of Dollars	
	Initial Investment	*Annual Operating*
Equipment		
Data processing equipment	524	52
Personnel		
Training	300	75
Pay and allowance	...	900
Maintenance	...	79
Intermediate commands	...	171
Overhead	...	426
TOTAL	824	1703

NOTE: This assumes 150 personnel, military or civilian, working in existing office facilities, living on their pay and allowances of $6000 per man per year.

Table 3

COMMUNICATIONS STATION

	Costs in Thousands of Dollars	
	Initial Investment	*Annual Operating*
Installations		
Equipment facilities	144	....
Personnel facilities	980	....
Maintenance	....	56
Equipment		
Mission equipment	598	60
Organizational equipment	381	23
Stocks		
Initial stock level	137	....
Readiness reserve	20	....
Spares	199	....
Transportation	40	90
Personnel		
Training	1120	280
Pay and allowances	....	896
Travel	56	10
Maintenance	....	90
Petroleum, oil, and lubricants	....	107
Services and miscellaneous	....	31
Intermediate commands	....	213
Overhead	....	618
TOTAL	3675	2474

NOTE: This assumes two 8-hr shifts for a mission personnel of 10 officers and 60 airmen; total personnel includes support of 40 officers and 240 airmen.

Table 4

INDEPENDENT LAUNCHING BASE (ALASKA)

	Costs in Thousands of Dollars	
	Initial Investment	*Annual Operating*
Installations		
Equipment facilities	1,091	.....
Personnel facilities	1,540	.....
Maintenance	......	132
Equipment		
12 Missiles	14,616	1,462
Ground equipment	1,250	188
Organizational equipment	598	36
Stocks		
Initial stock level	214	.....
Readiness reserve	33	.....
Spares	4,872	.....
Transportation	345	201
Personnel		
Training	1,760	440
Pay and allowances	......	1,408
Travel	88	15
Maintenance	......	2,192
Petroleum, oil, and lubricants	......	168
Services and miscellaneous	......	48
Intermediate commands	......	732
Overhead	......	2,340
TOTAL	26,407	9,362

NOTE: This assumes a single shift with 10 officers and 100 airmen as mission personnel; total personnel includes support of 40 officers and 400 airmen.

Table 5

TECHNICAL MANPOWER REQUIREMENTS FOR THE OPERATIONAL FEED BACK SYSTEM

Operation or Function	Officers	Airmen
Launching Base		
Satellite subsystems test and installation (reconnaissance, communications and guidance equipment, auxiliary powerplant)	3	25
Propulsion systems test and installation	1	10
Vehicle assembly and systems test	2	20
Prelaunch checkout and launching	2	20
Propellant storage and handling	0	5
Ground handling	0	5
Ground communications	1	10
Ground tracking	0	3
TOTAL	9	98
Communications Station		
Tracking and control	1	4
Programming and computing	2	4
Display and storage	0	5
Communications and cryptography	1	10
Maintenance	1	7
TOTAL (per shift)	5	30

Intelligence Center

Operation or Function	Number of Men
Selection	15
Interpretation and analysis	150
Communications	10
Photo laboratory	30
Clerical and files	20
TOTAL	225

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WASHINGTON DC 20330-1000

OFFICE OF THE SECRETARY

14 November 1995

MEMORANDUM FOR SAF/SXP (Col Cox)

FROM: SAF/PAS

SUBJECT: Declassification of Rand Documents

Subject Rand documents (R-262, Vol I and II; R-218; RM-1811; RM-2012; and R-217) have been reviewed by SAF/AAZD and were determined to be unclassified. The subject matter refers to programs which preceded the Corona program which is now being released through the National Archives. No sources or methods still requiring protection were noted and, from an Air Force standpoint, there is no objection to public release.

POC is Carol Rose, 697-3222.

JUNE F. FORTE
Chief, Office for Security Review
Office of Public Affairs

Ada 340556
Ada 340560

Attachment:
Rand Documents (SAF/PAS 95-1031)

Larry Downing
427-0011

→ Please ensure all Classification Markings are removed prior to release.

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